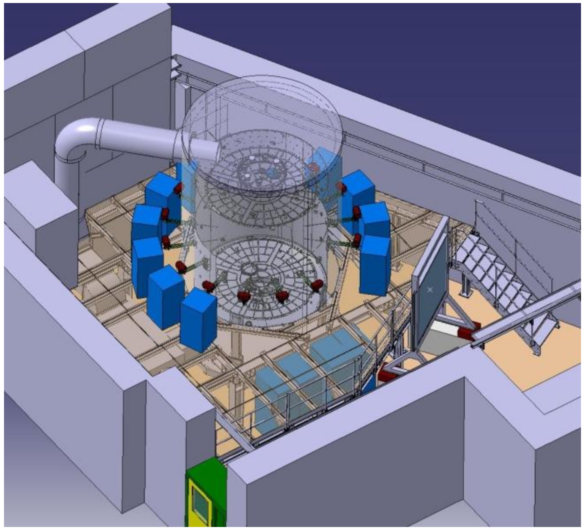
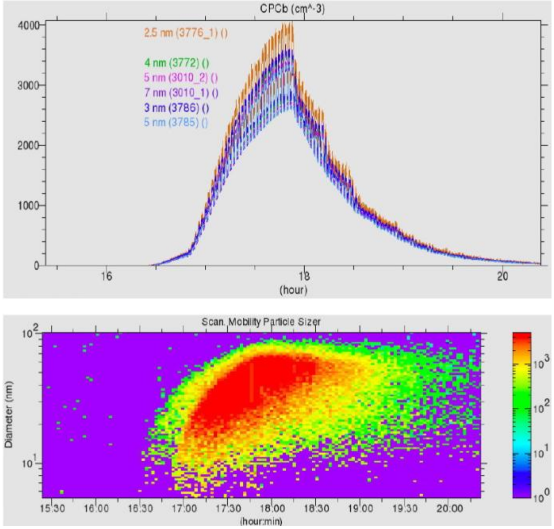
The construction and the first run of the CLOUD experiment

DT Science-Techno Tea meeting, 12 May 2010

Antti Onnela (PH-DT), Jonathan Duplissy (PH-SME-CL)





CLOUD collaboration

19 institutes:

University of Innsbruck, Institute of Ion Physics and Applied Physics, **Austria**
University of Vienna, Institute for Experimental Physics, **Austria**
Institute for Nuclear Research and Nuclear Energy, Sofia, **Bulgaria**
University of Tartu, Department of Environmental Physics, Tartu, **Estonia**
Helsinki Institute of Physics and University of Helsinki, Department of Physics, **Finland**
Finnish Meteorological Institute, Helsinki, **Finland**
University of Kuopio, Department of Applied Physics, **Finland**
Tampere University of Technology, Department of Physics, **Finland**
Goethe-University of Frankfurt, Institute for Atmospheric and Environmental Sciences, Frankfurt am Main, **Germany**
Leibniz Institute for Tropospheric Research, Leipzig, **Germany**
University of Lisbon, Department of Physics, **Portugal**
Lebedev Physical Institute, Solar and Cosmic Ray Research Laboratory, Moscow, **Russia**
CERN, Physics Department, **Switzerland**
Fachhochschule Nordwestschweiz (FHNW), Inst. Aerosol & Sensor Technology, Brugg, **Switzerland**
Paul Scherrer Institut, Laboratory of Atmospheric Chemistry, **Switzerland**
University of Leeds, School of Earth and Environment, **United Kingdom**
University of Reading, Department of Meteorology, **United Kingdom**
Rutherford Appleton Laboratory, Space Science & Particle Physics Departments, **United Kingdom**
California Institute of Technology, Division of Chemistry and Chemical Engineering, **USA**

CERN involvement:
- PH-SME-CL
- PH-DT: Gas system, Thermal system, HV field cage, Infrastructure, Technical coordination
- EN-MME
- EN-MEF
- EN-CV
- TE-VSC

Agenda

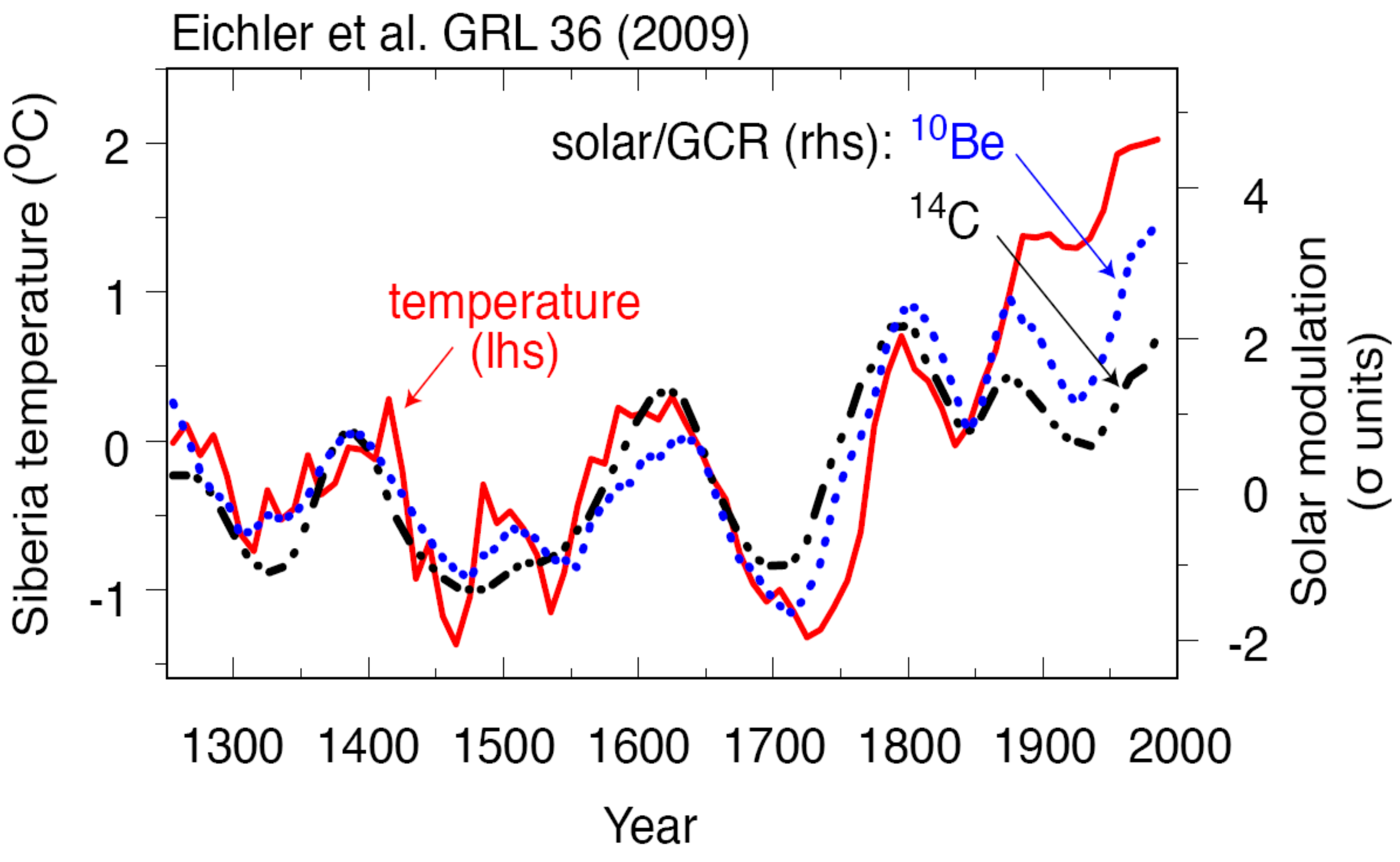
- Background: Cosmic rays, aerosols and climate
- CLOUD Concept
- CLOUD Facility
- CLOUD Measurement instruments
- First run in 2009
- Plans for 2010 and beyond

Cosmic rays and climate ?

- Numerous correlations suggest GCR-climate connection but no established physical link.

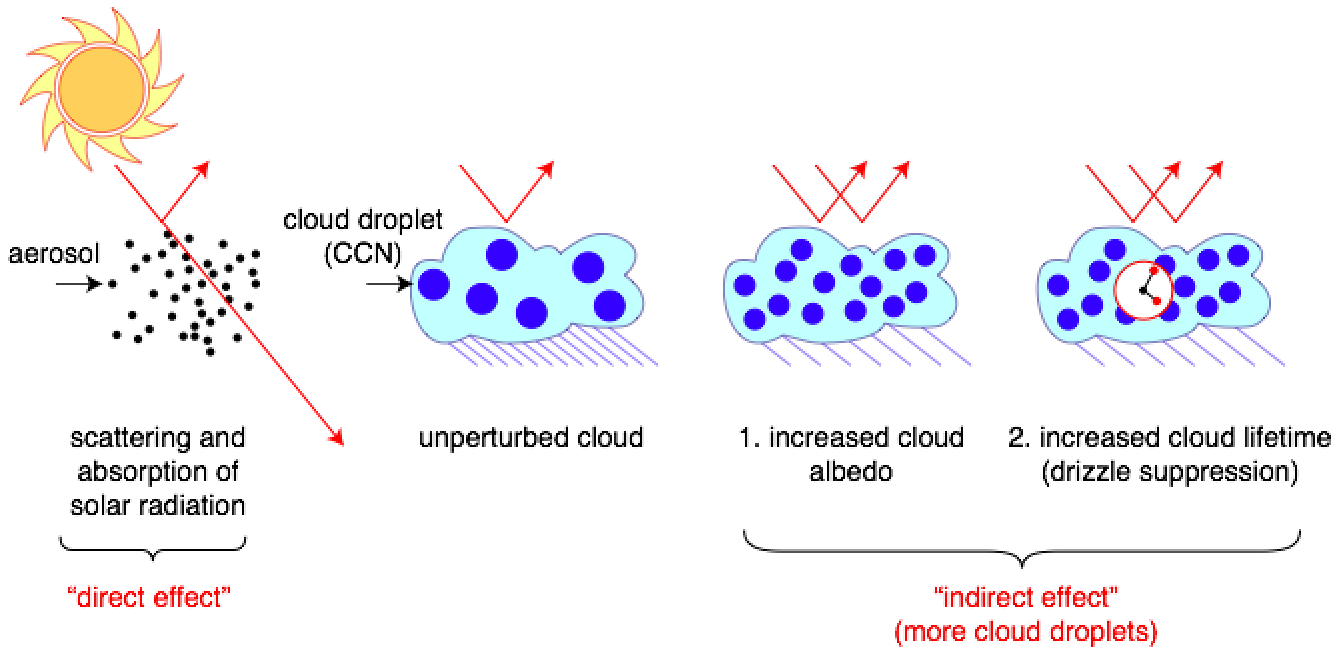
Very recent observation by Eichler et al., ACP, 2009:

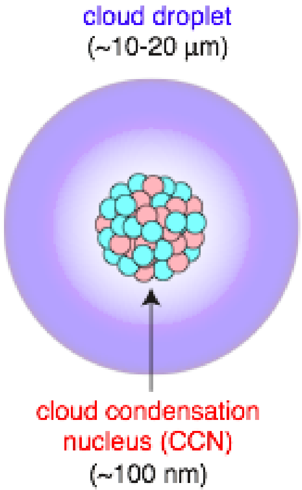
Correlation between GCRs and temperature in Siberia from glacial ice core data.



Slide courtesy of J.Curtius

Maybe the link between Cosmic rays and Climate is via aerosols? (1/2)





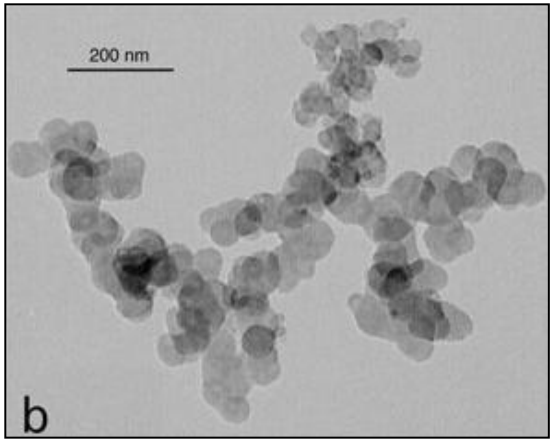
- All cloud droplets form on aerosol "seeds" known as cloud condensation nuclei - CCN
- Cloud properties are sensitive to number of droplets
- More aerosols/CCN:
  - Brighter clouds, with longer lifetimes
- Sources of atmospheric aerosols:
  - Primary (dust, sea salt, fires)
  - Secondary (gas-to-particle conversion)

Slide courtesy of J.Kirkby

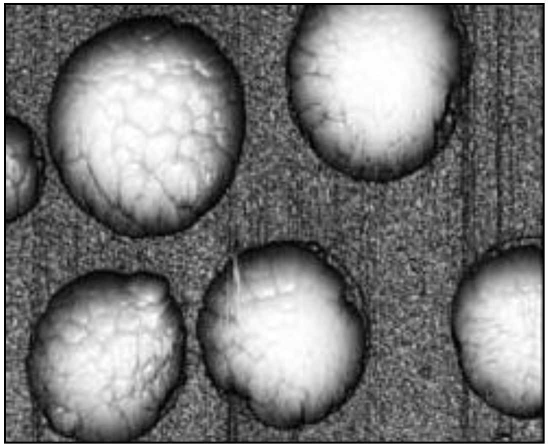
What is an aerosol?

<u>Definition:</u> Suspension of small (liquid or solid) particles in a gas

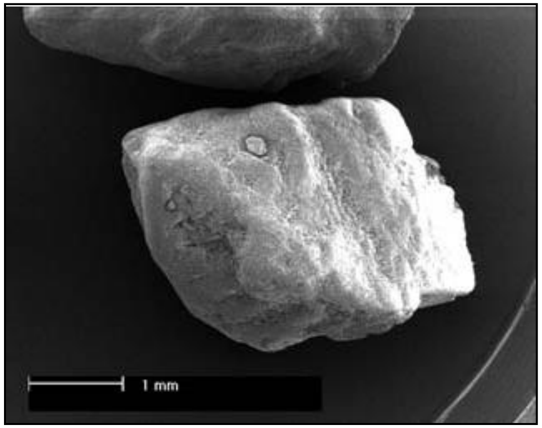
Diesel soot: ca. 0.1 μm



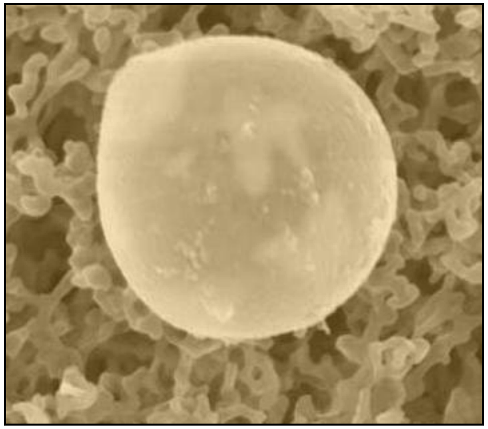
Ammonium sulfate: ca. 0.1 μm



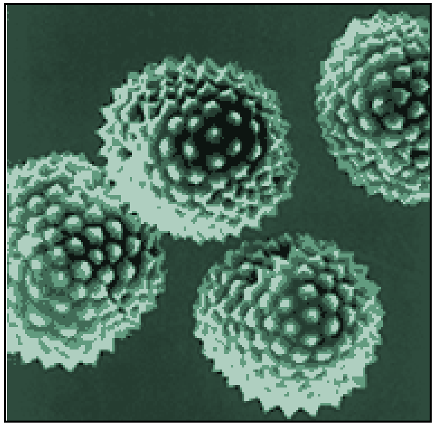
Sea salt: 0.2 - 10 μm



Mineral dust: 0.2 - 10 μm

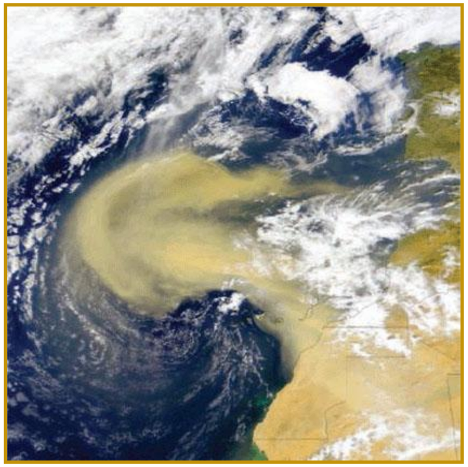


Pollen: 10 - 100 μm



Primary Aerosol Sources

Sea spray



Mineral dust

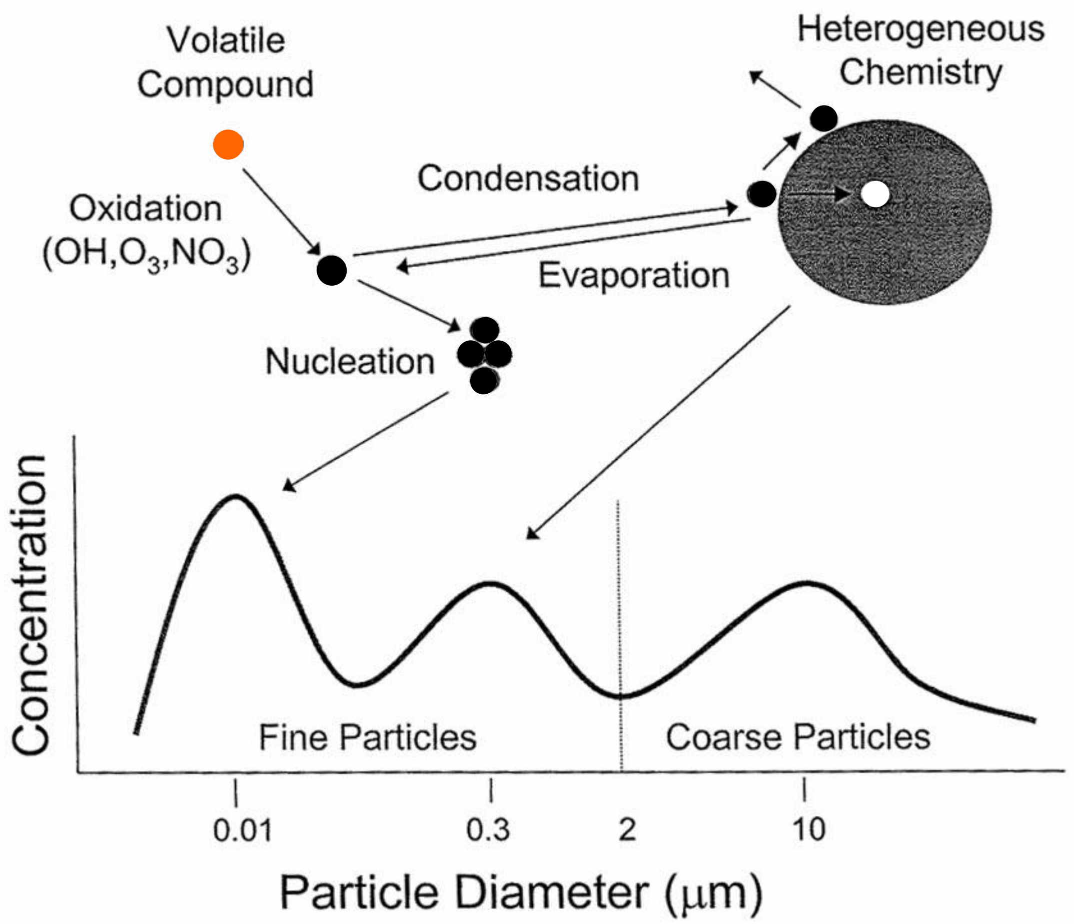
Volcano ► Sulfates, dust

Biomass burning ► Organics

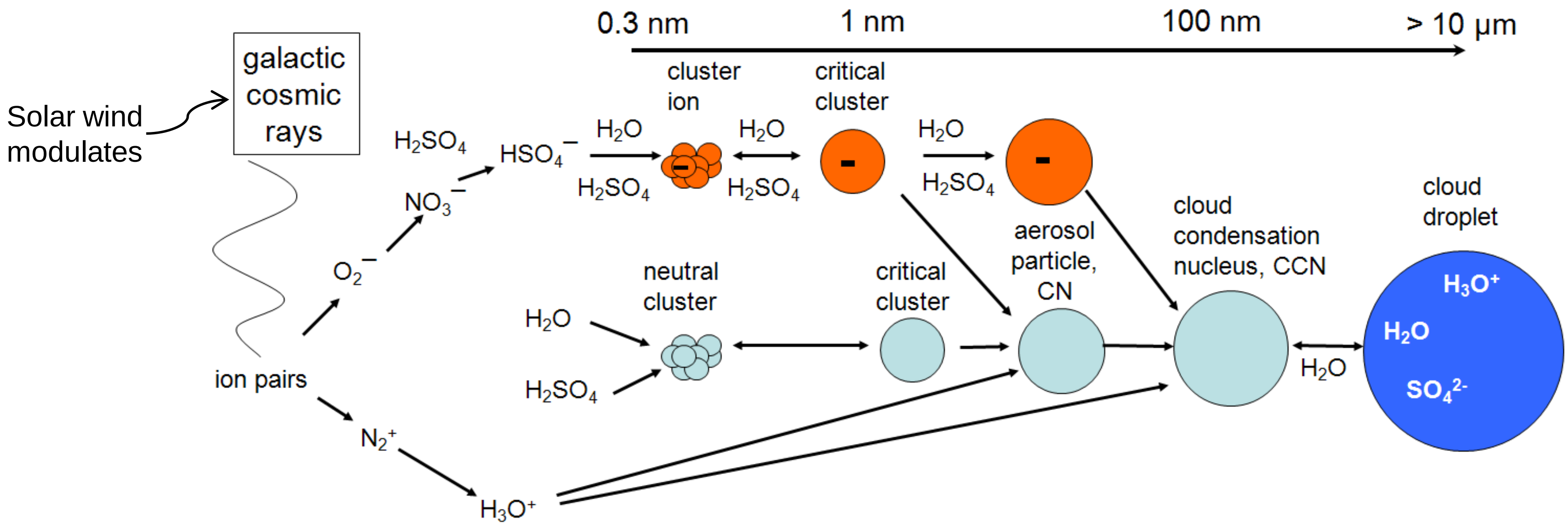
Traffic emissions ► Soot

Industrial Emissions

Secondary Aerosol Formation

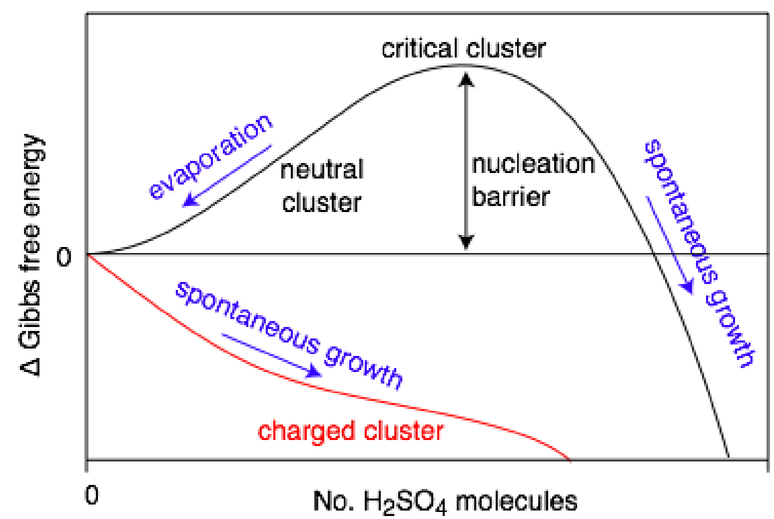


Maybe the link between Cosmic rays and Climate is via aerosols? (2/2)



- Secondary (gas-to-particle conversion) aerosol formation: Trace condensable vapour → CN → CCN
- But contributing vapours and nucleation rates poorly known
- H_2SO_4 is thought to be the primary condensable vapour in atmosphere (sub ppt)
- Ion-induced nucleation pathway is energetically favoured but limited by the ion production rate and ion lifetime
- *Candidate mechanism for solar-climate variability*

– ***This is now studied by CLOUD***



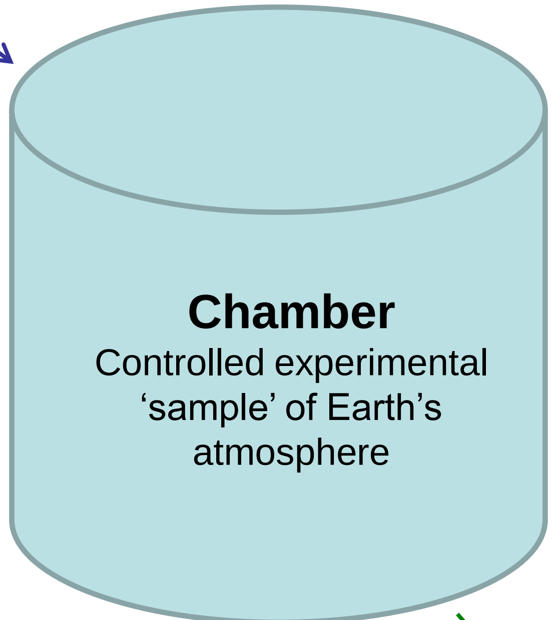
CLOUD experiment concept

1. Fill chamber with
   clean air
   + water vapour

2. Set temperature and pressure

3. Add trace gases, condensable species (in extremely low concentrations)

4. Expose to ionizing beam, and possibly to UV-light

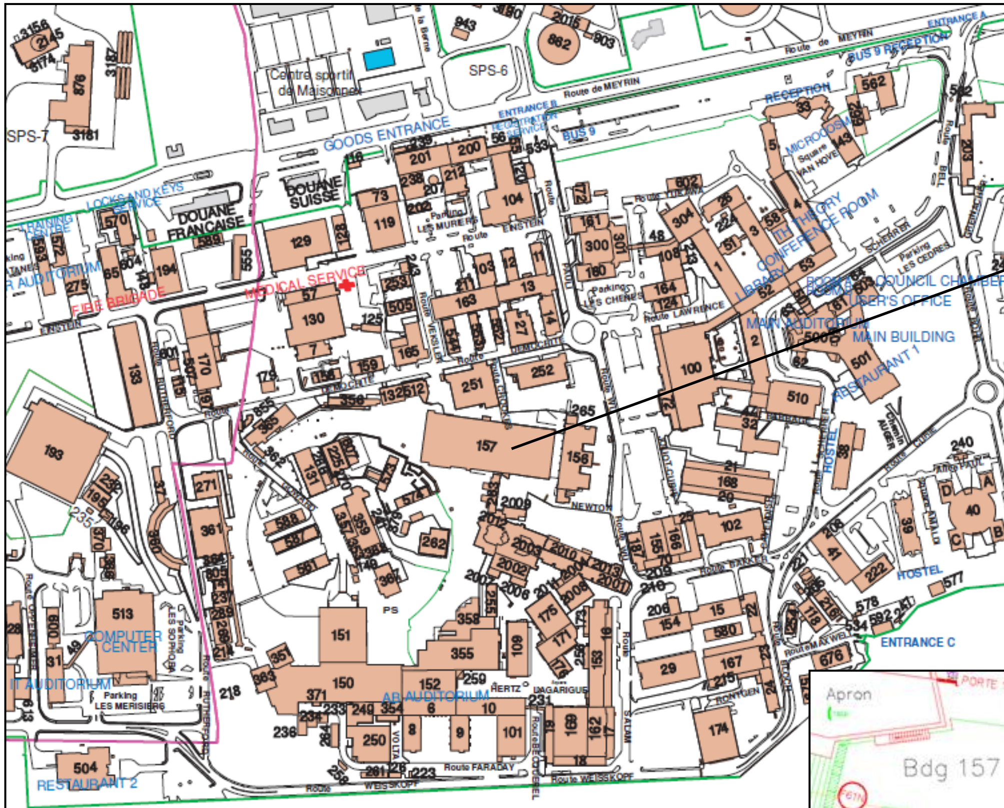


5. Observe
   - Particle growth size distribution
   - Electrical charge distribution
   - Cloud droplet/ice particle concentrations,
   - etc.

6. Repeat experiment (typically hours), possibly with varying parameters

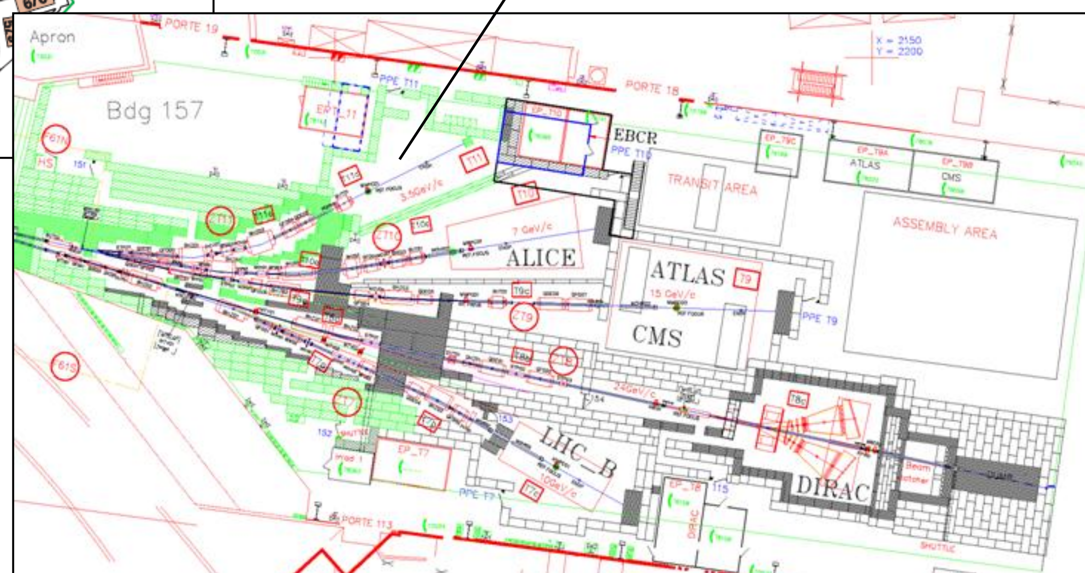
7. Carefully flush the chamber and clean the chamber walls between experiments

CLOUD in PS-T11



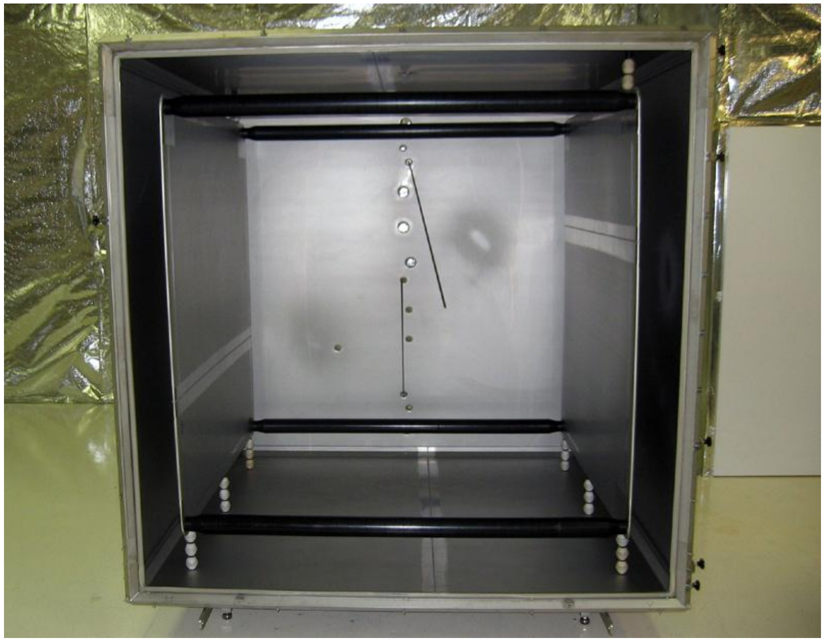
PS East Hall

T11 beam area
(3.5 GeV/c)



CLOUD-06 prototype

- First prototype measurement campaign took place in Oct/Nov 2006:
  - 8 m^3 chamber, stainless steel and teflon
  - Ultrapure air supply, field cage, UV illumination through PTFE-foil
  - Various analytical instruments (beam, gases, ions, aerosol)



- Numerous nucleation events observed, but problems with:
  - Lack of measurement reproducibility
  - Surface cleanliness
  - Insufficient thermal control
- Valuable technical lessons for CLOUD-09 design

CLOUD-09

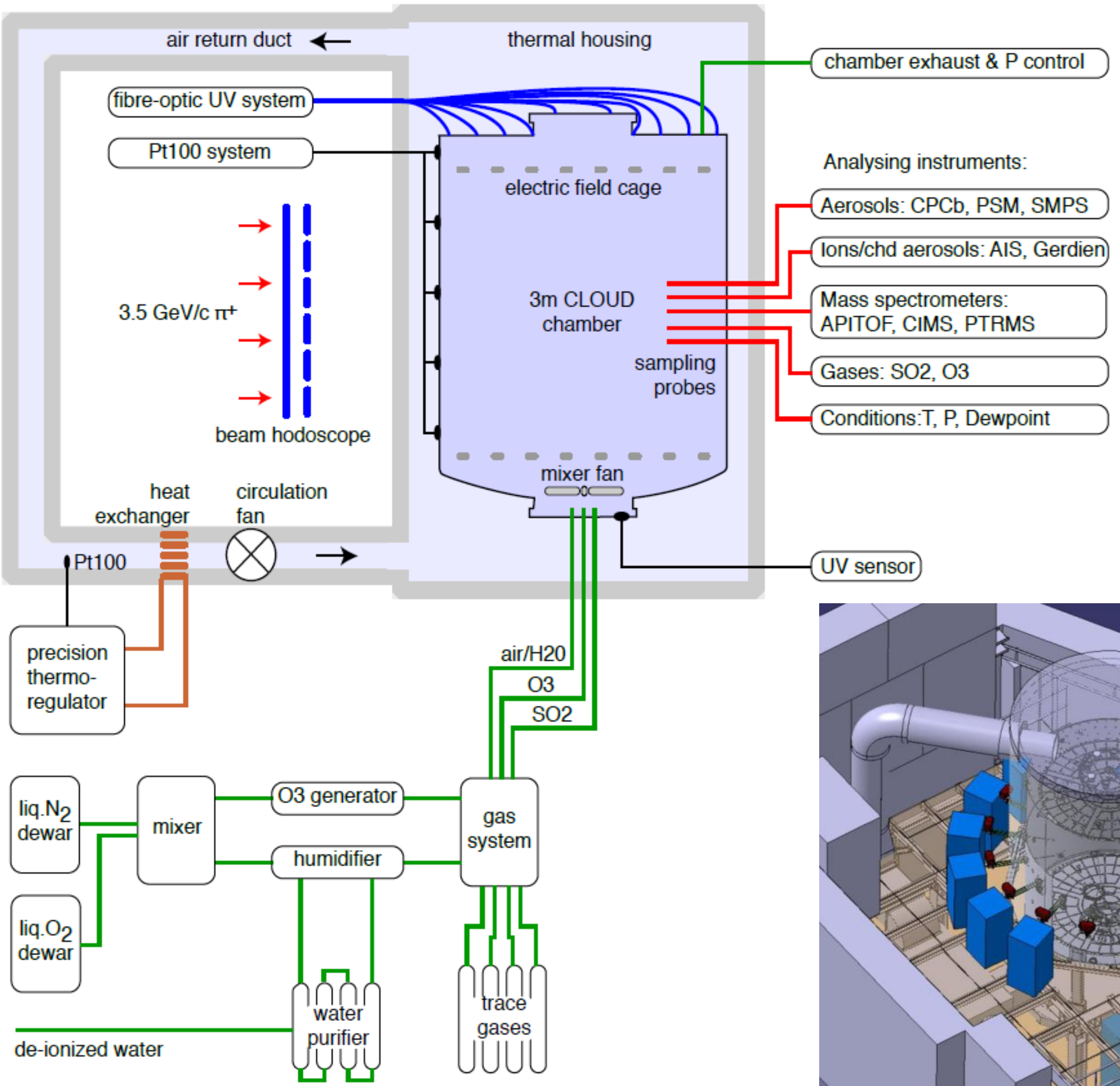
- Based on results from the CLOUD-06 prototype the design of the CLOUD-09 chamber has been developed.

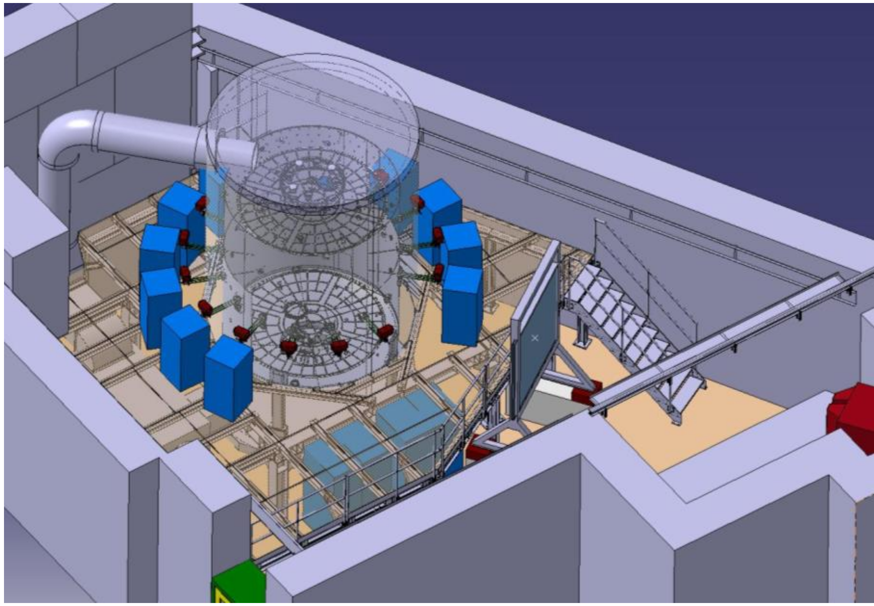
Unique capabilities:

- temperature stability: <0.1°C
- temperature range: -90°C to +30°C; cleaning at +100°C
- surface cleanliness: <10 pptv organics contamination, stainless steel (and gold), no teflon, no O-rings
- ultrapure gas supplies
- UV system: negligible heat load by use of fibre optics.
- field cage 30 kV/m

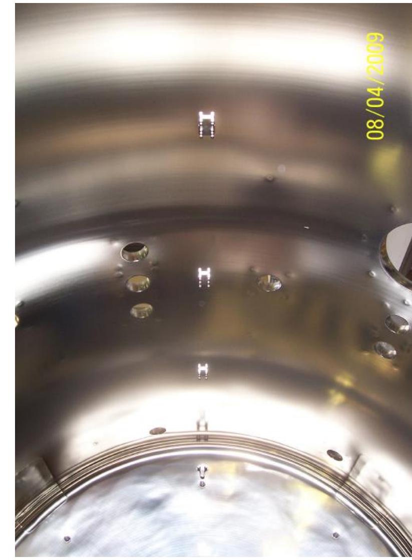
Highly advanced aerosol chamber already as such!

CLOUD-09


air return duct
thermal housing
fibre-optic UV system
Pt100 system
chamber exhaust & P control
Analysing instruments:
Aerosols: CPCb, PSM, SMPS
Ions/chd aerosols: AIS, Gerdien
Mass spectrometers:
APITOF, CIMS, PTRMS
Gases: SO2, O3
Conditions:T, P, Dewpoint
electric field cage
3m CLOUD
chamber
sampling
probes
3.5 GeV/c π+
beam hodoscope
mixer fan
heat
exchanger
circulation
fan
Pt100
UV sensor
precision
thermo-
regulator
air/H20
O3
SO2
liq.N2
dewar
mixer
O3 generator
humidifier
gas
system
liq.O2
dewar
water
purifier
trace
gases
de-ionized water

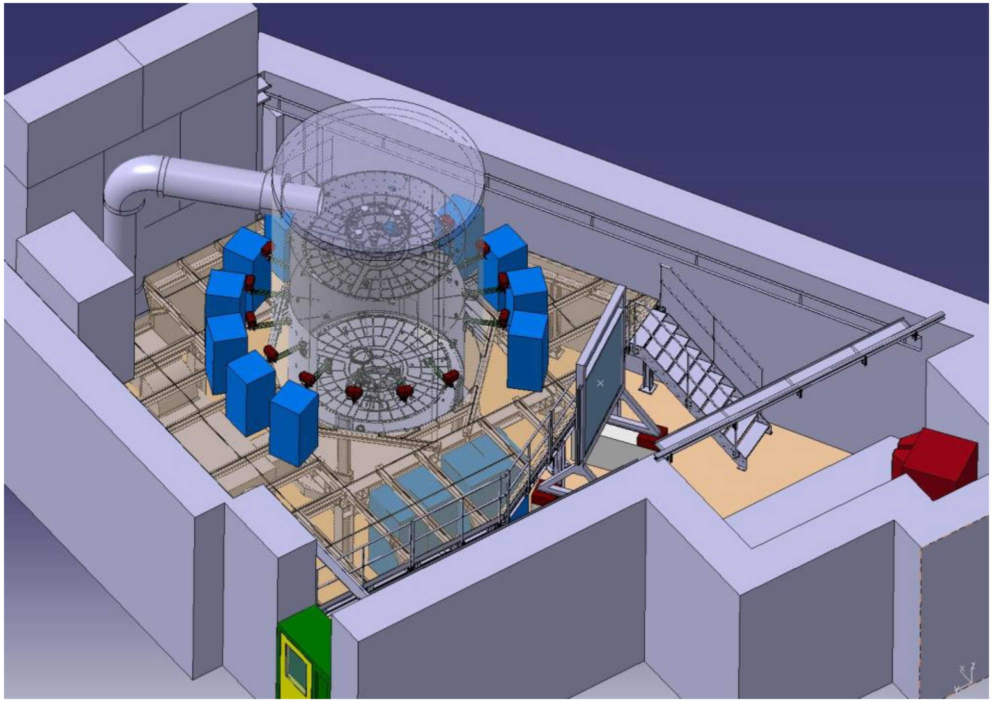


CLOUD Aerosol chamber

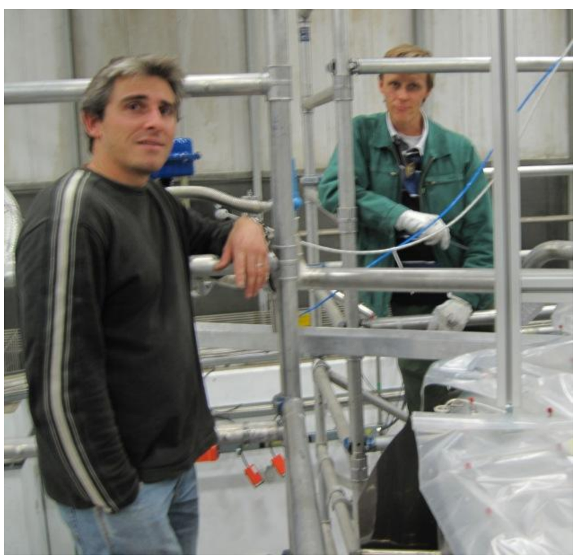


- 27 m^3
- Pressure: Atmospheric ± 0.3 bar
- Only metallic seals
- Electropolished inner surfaces

T11 area rearranged for CLOUD

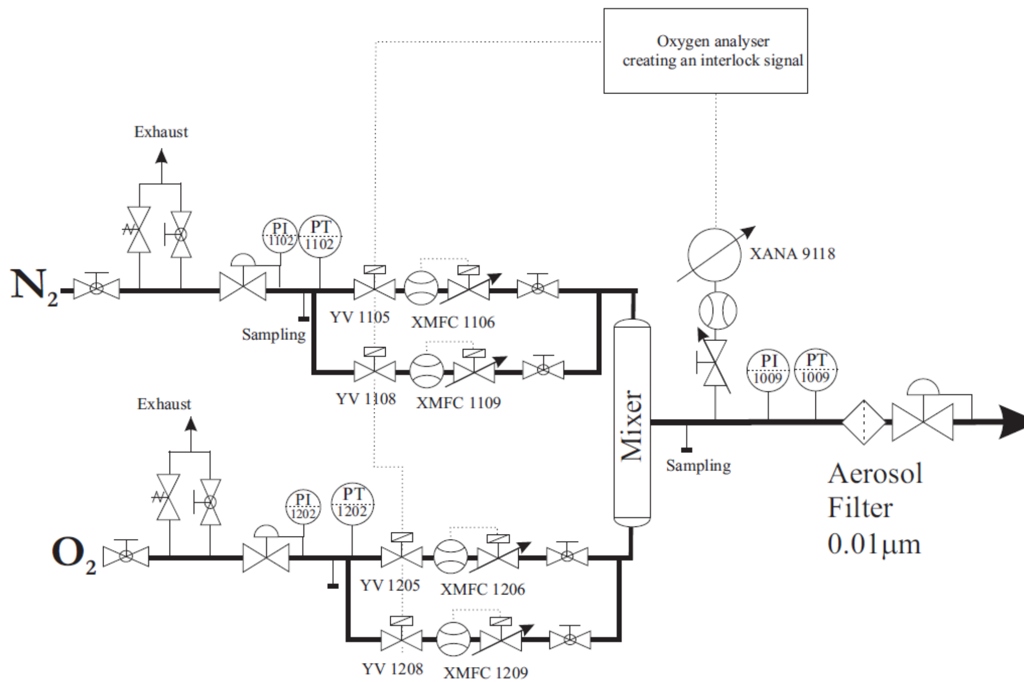


Aerosol chamber in T11

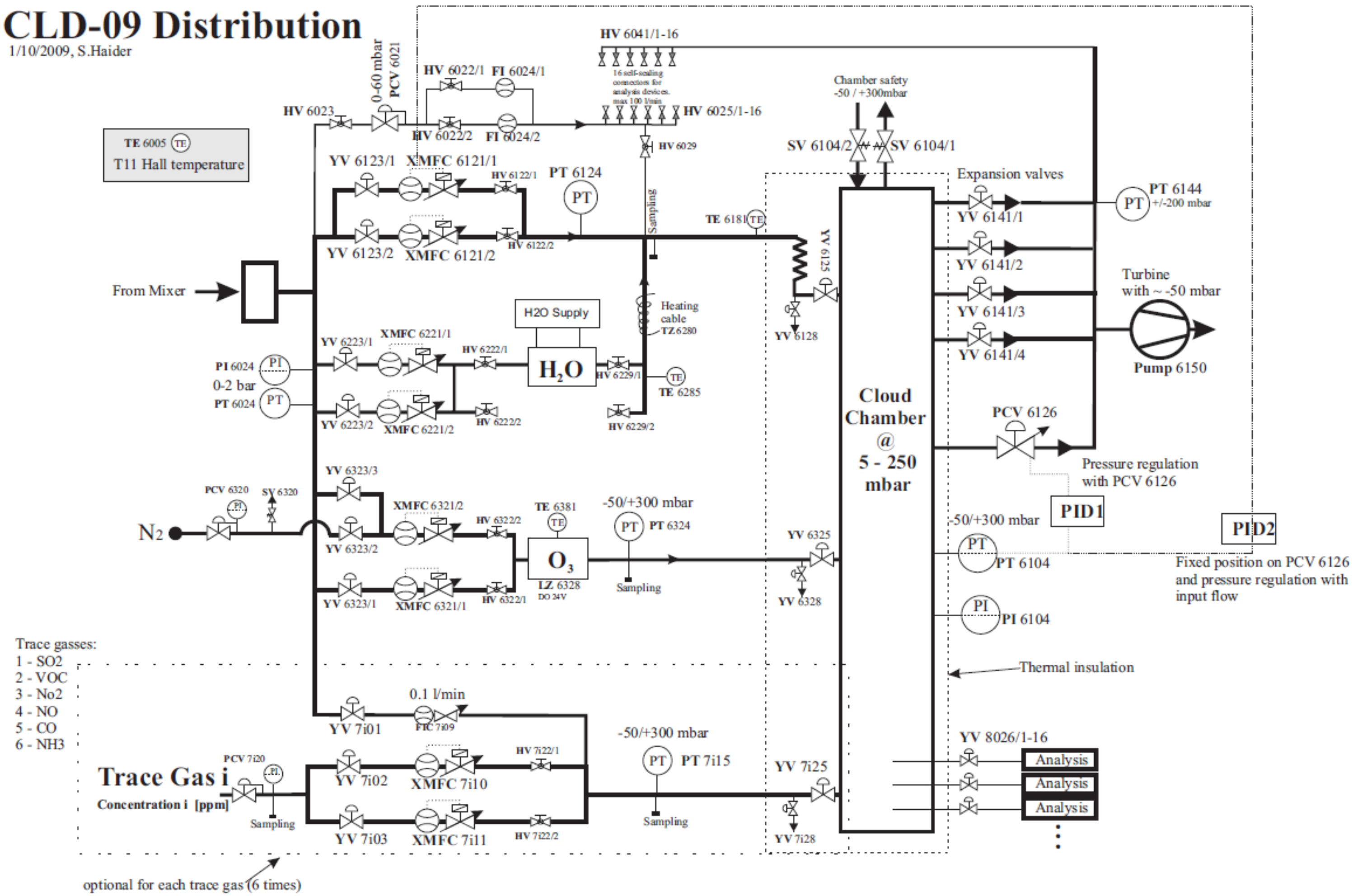


Caillebotis #!&?
... November 2009!

Ultra-pure air

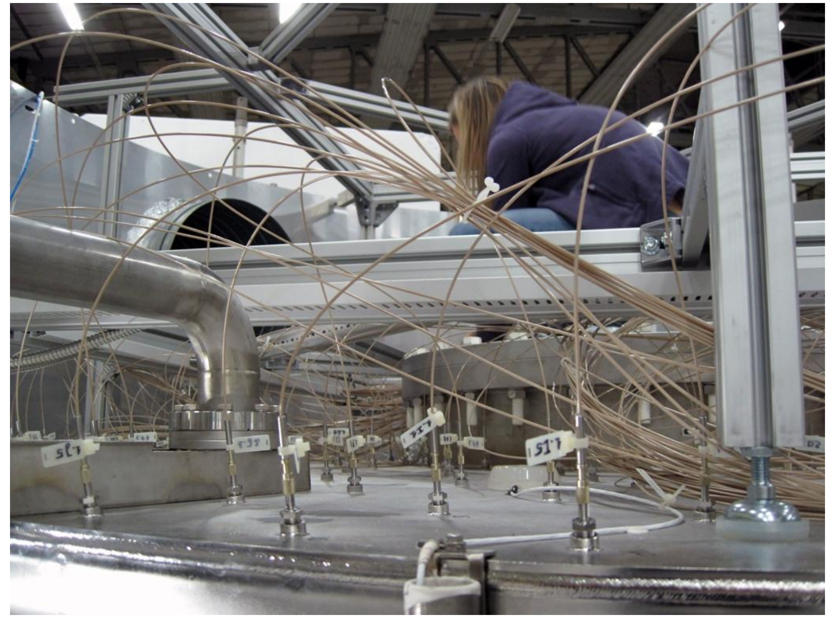


Gas system



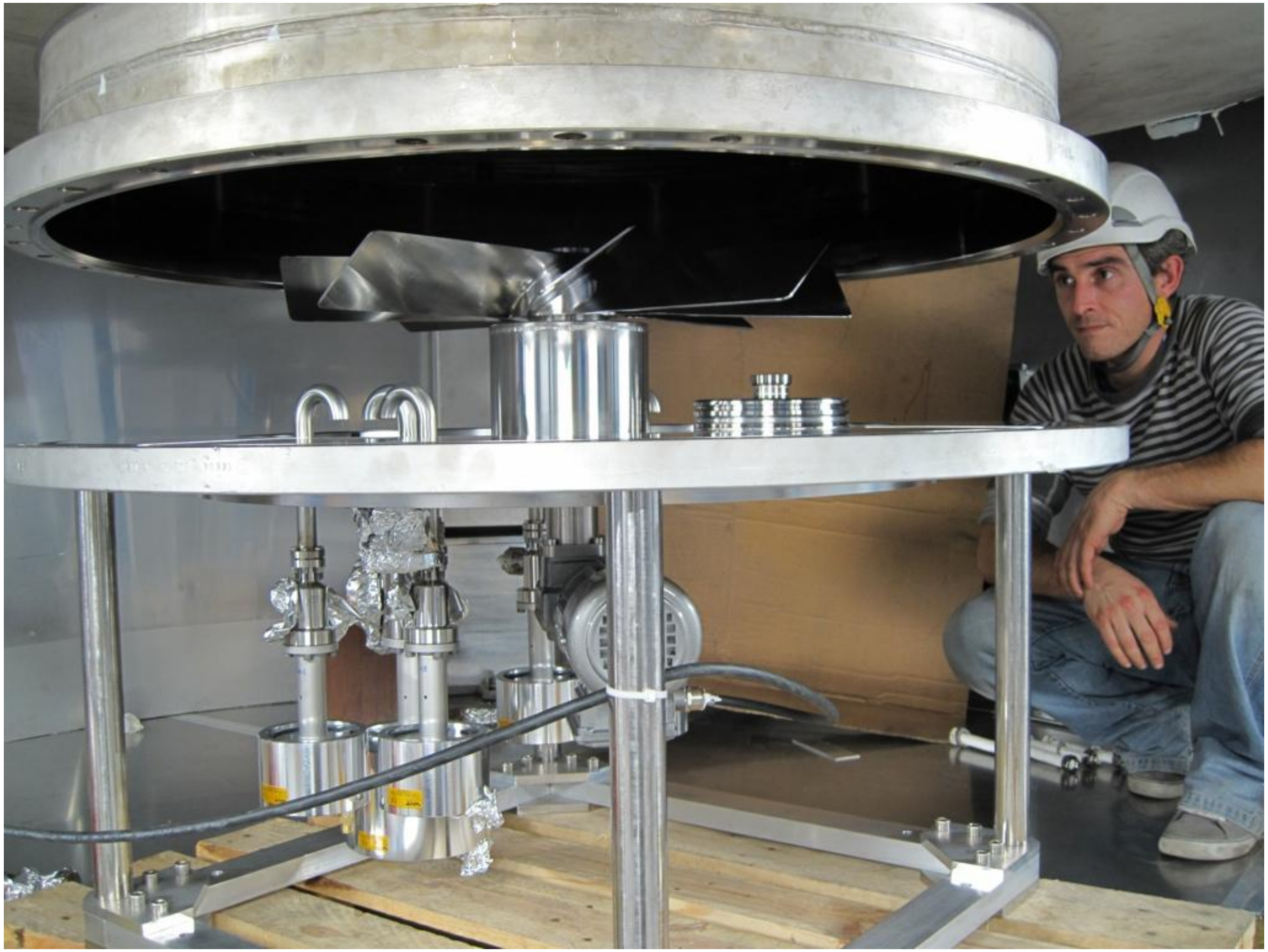
CLD-09 Distribution
1/10/2009, S.Haider
TE 6005
T11 Hall temperature
From Mixer
HV 6023
0-60 mbar
PCV 6021
HV 6022/1
FI 6024/1
HV 6022/2
FI 6024/2
HV 6041/1-16
HV 6025/1-16
HV 6029
Chamber safety
-50 / +300mbar
SV 6104/2
SV 6104/1
YV 6123/1
XMFC 6121/1
PT 6124
YV 6123/2
XMFC 6121/2
TE 6181
YV 6125
YV 6128
Expansion valves
YV 6141/1
YV 6141/2
YV 6141/3
YV 6141/4
PT 6144
+/-200 mbar
Turbine
with ~ -50 mbar
Pump 6150
H2O Supply
Heating cable
YV 6223/1
XMFC 6221/1
PI 6024
0-2 bar
PT 6024
YV 6223/2
XMFC 6221/2
HV 6222/2
TE 6285
Cloud
Chamber
@
5 - 250
mbar
PCV 6126
Pressure regulation
with PCV 6126
PID1
PID2
Fixed position on PCV 6126
and pressure regulation with
input flow
YV 6323/3
PCV 6320
SV 6320
N2
XMFC 6321/2
TE 6381
-50/+300 mbar
PT 6324
YV 6323/2
O3
YV 6323/1
XMFC 6321/1
Sampling
YV 6325
YV 6328
-50/+300 mbar
PT 6104
PI 6104
Thermal insulation
Trace gasses:
1 - SO2
2 - VOC
3 - No2
4 - NO
5 - CO
6 - NH3
0.1 l/min
YV 7i01
FIC 7i09
-50/+300 mbar
Trace Gas i
Concentration i [ppm]
PCV 7i20
YV 7i02
XMFC 7i10
PT 7i15
YV 7i25
YV 8026/1-16
Analysis
Analysis
Analysis
YV 7i03
XMFC 7i11
HV 7i22/2
YV 7i28
optional for each trace gas (6 times)

UV system

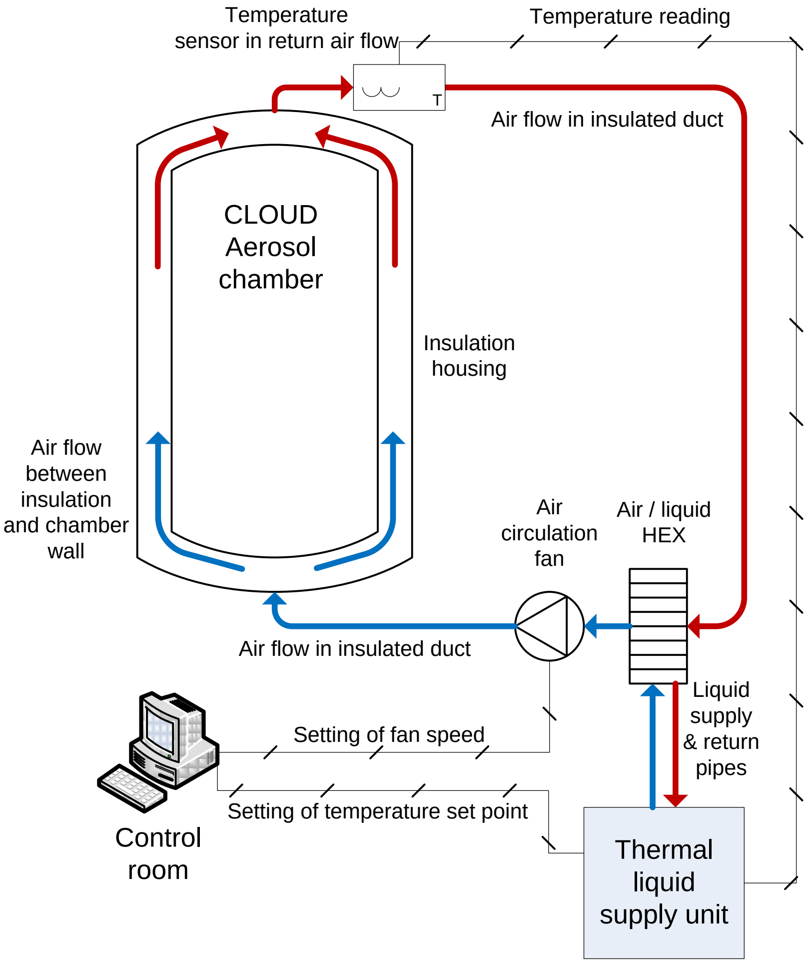


HV field cage

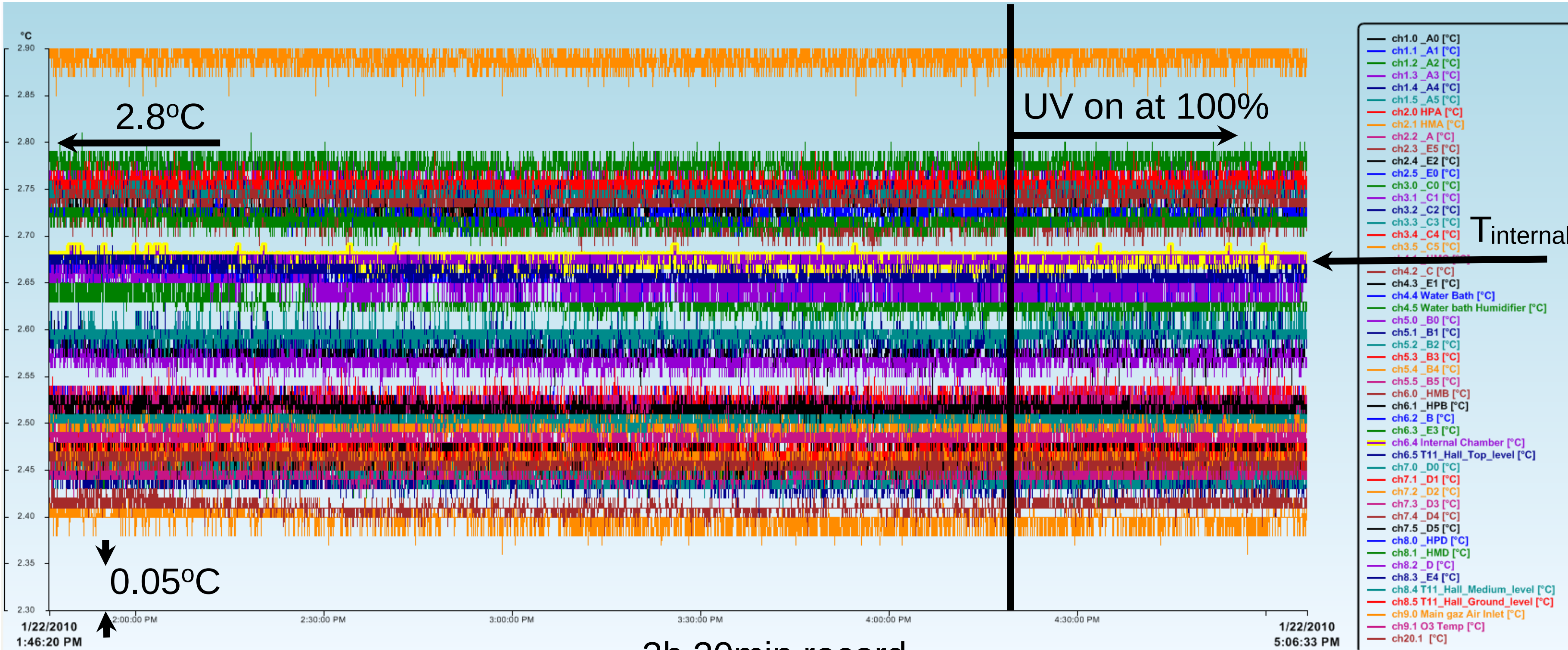
Mixing fan



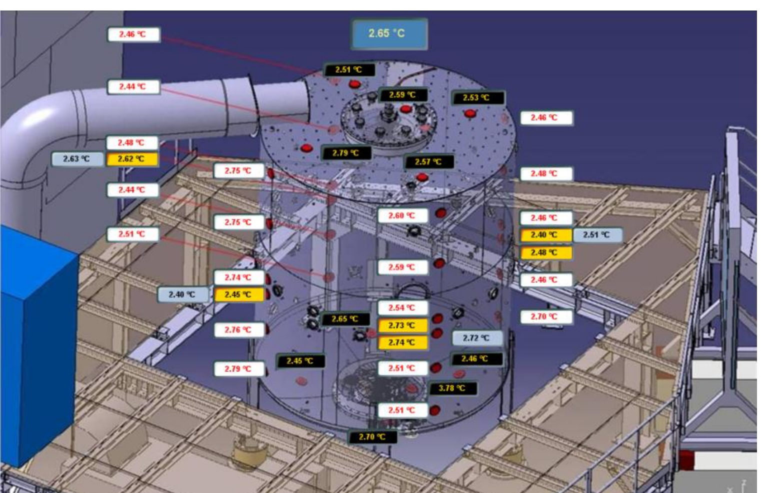
Thermal system



Temperature stability

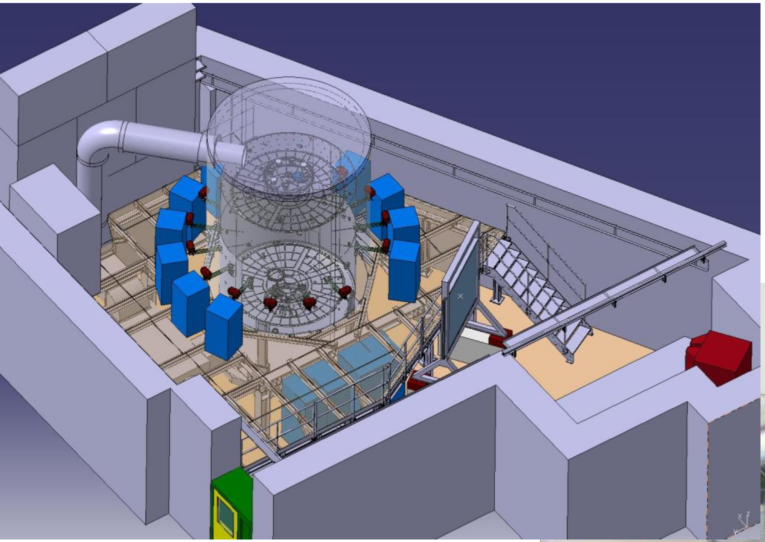


3h 20min record



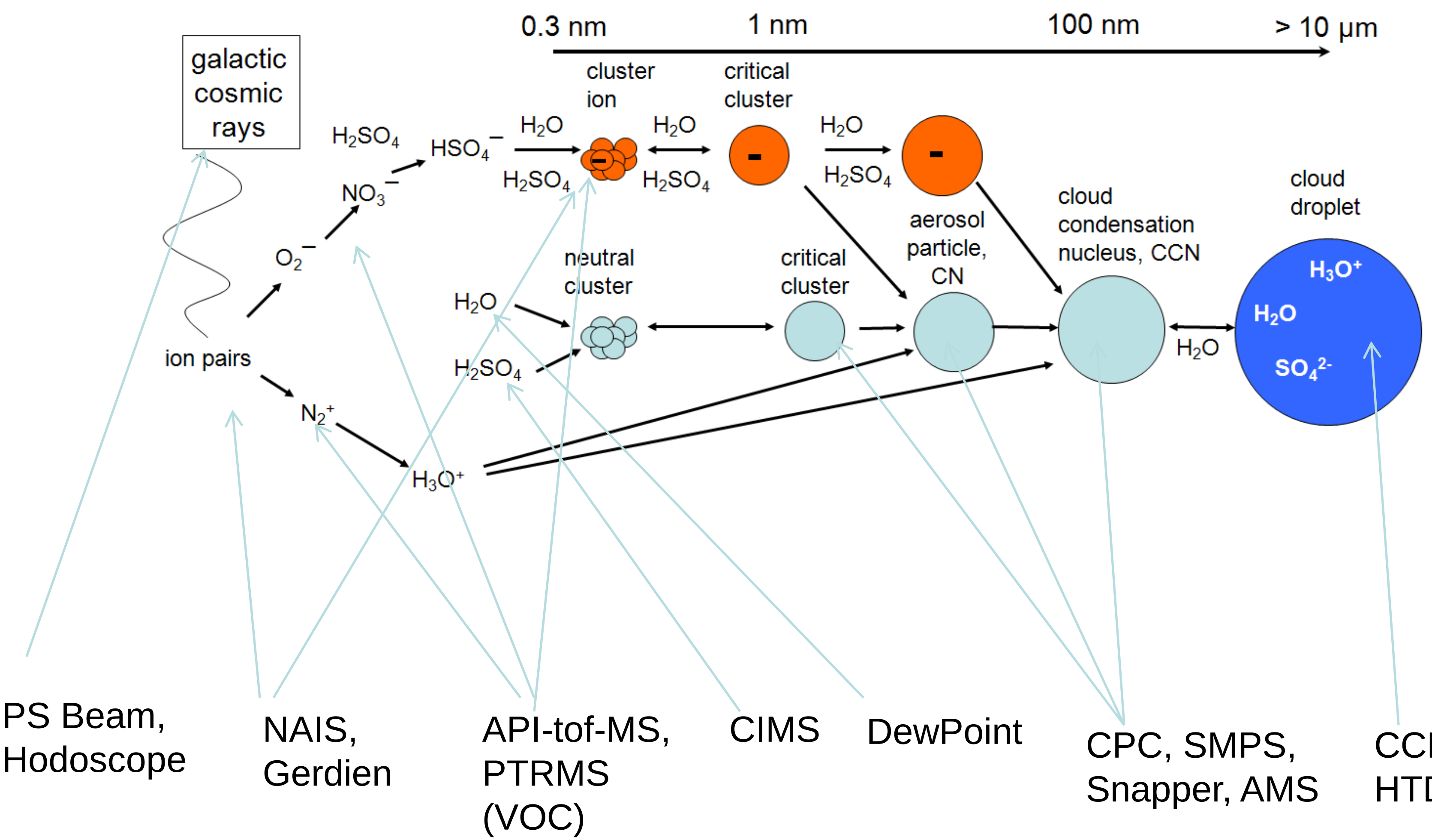
- Chamber walls & internal temperature stable to ~0.01°C over long periods
- No temperature change when UV lights turned on at 100%
- No T-induced nucleations were observed during entire campaign
- All 2009 beam runs were made at +19°C

CLOUD in Nov-Dec 2009 beam run

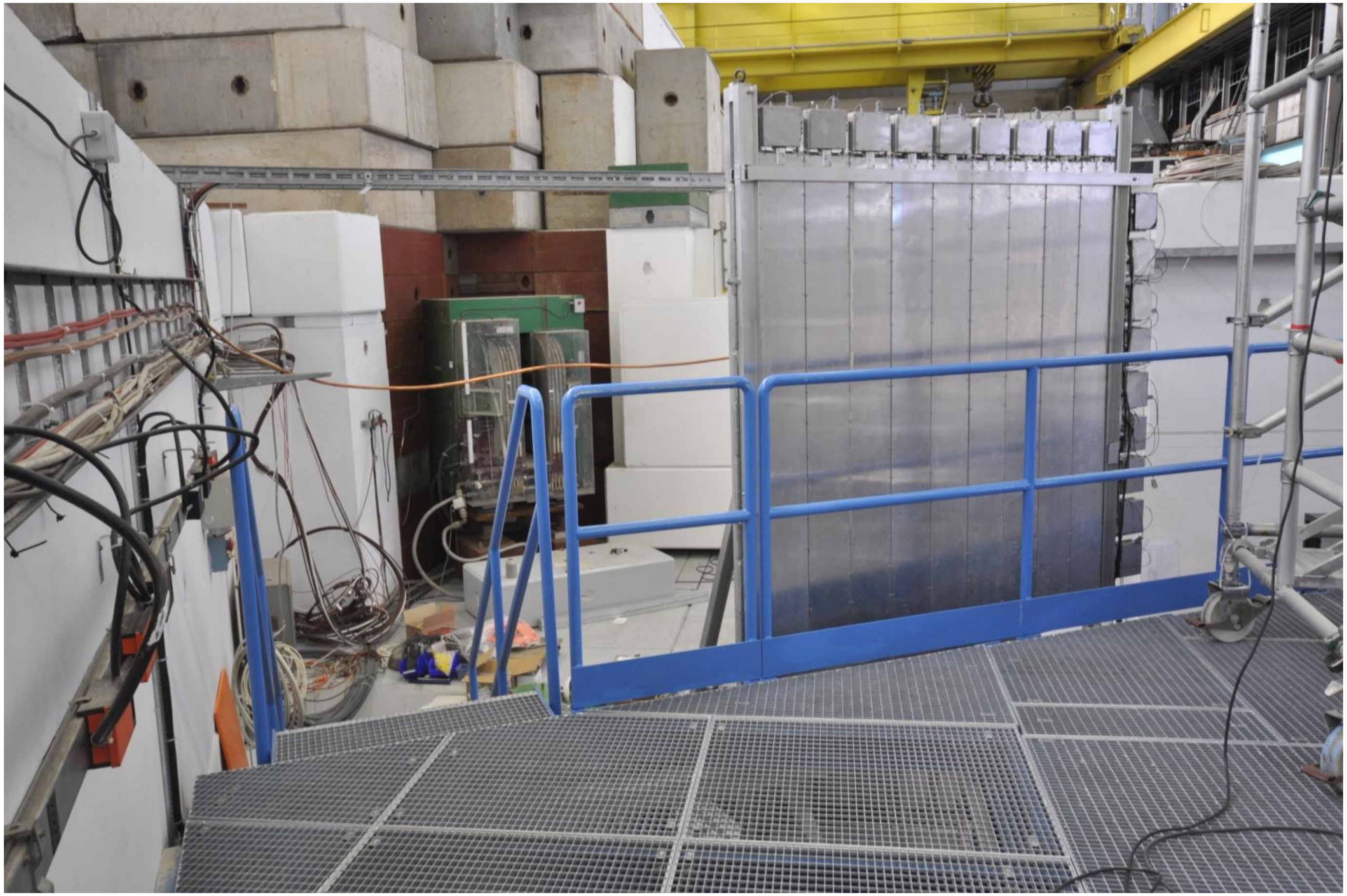


CLOUD Measurement instruments

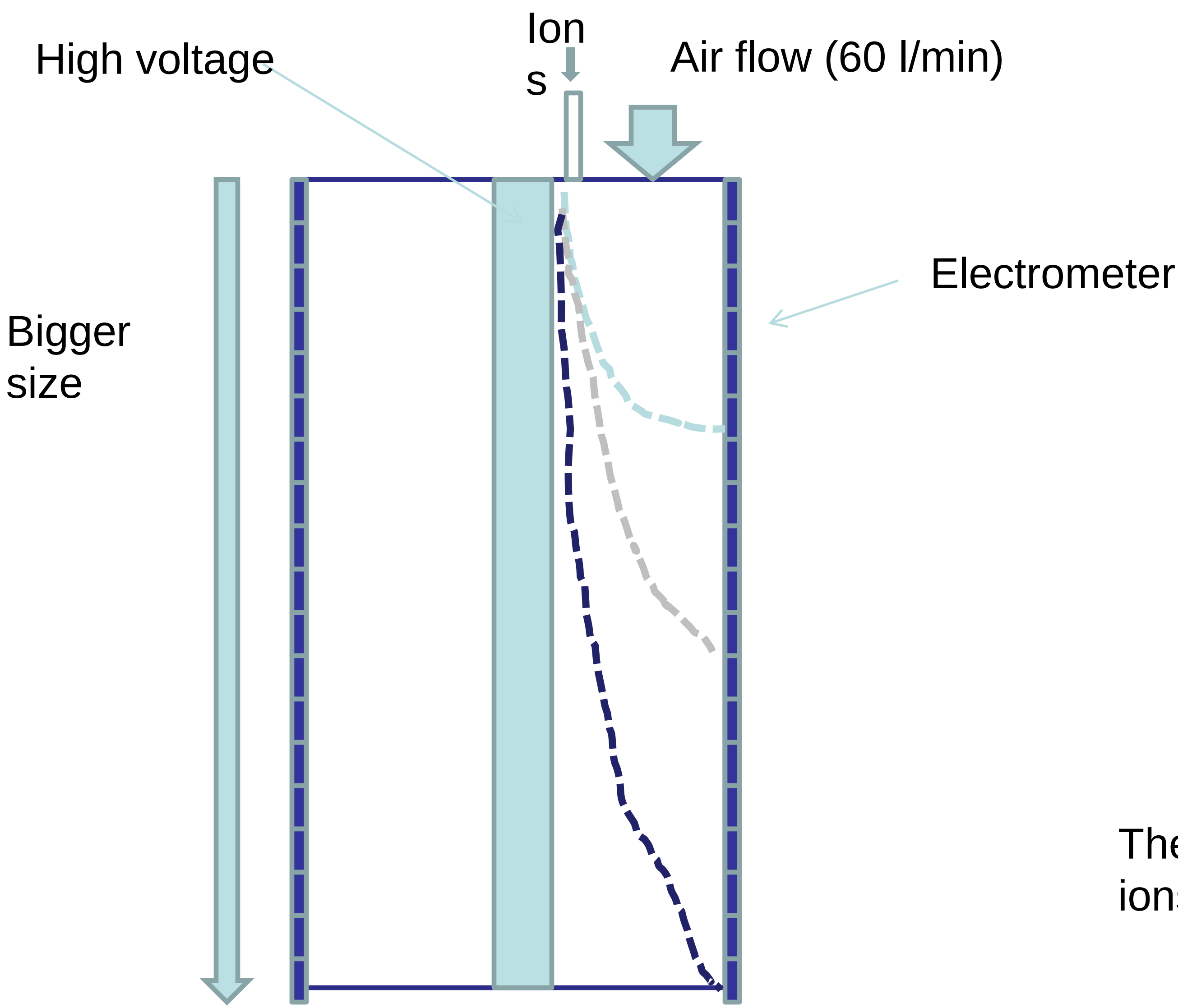
Aerosols from gas-to-particle conversion / Cosmic rays



Hodoscope



AIS principle



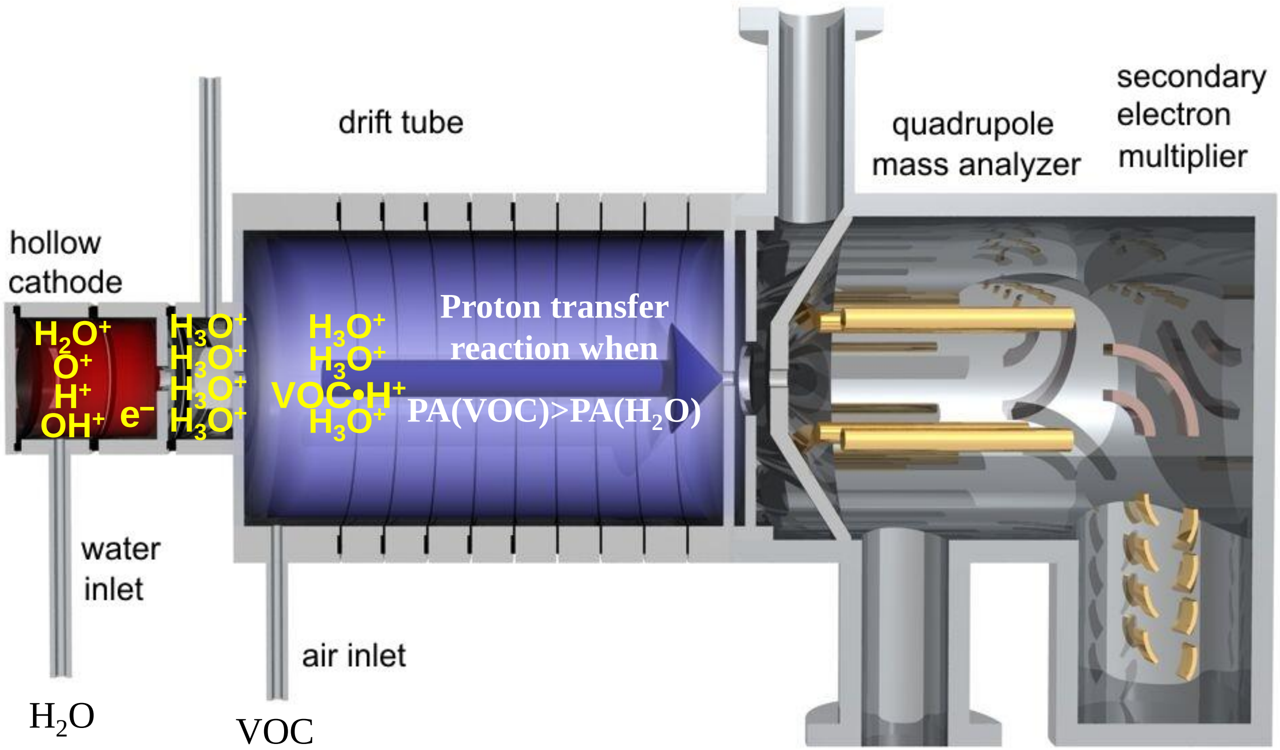
The AIS measures the ions distribution

Pictures from: A.I.S. manual

PTR-MS

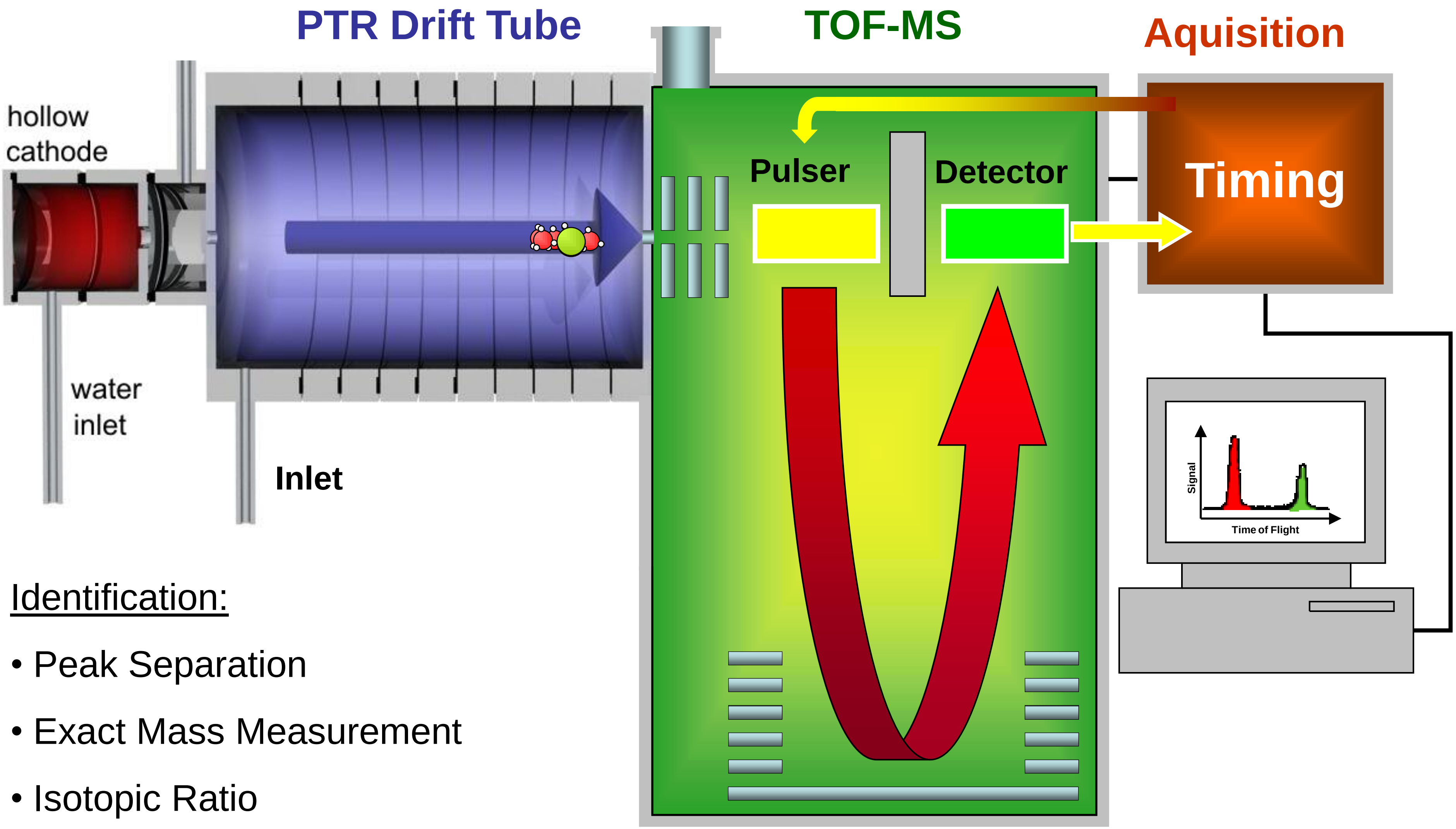
PTR-MS How does it work?

$$H_3O^+ + VOC \rightarrow VOCH^+ + H_2O$$ pseudo first-order kinetics



$$[VOC] = \frac{i(VOCH^+)}{i(H_3O^+)} \frac{1}{k\,t}$$

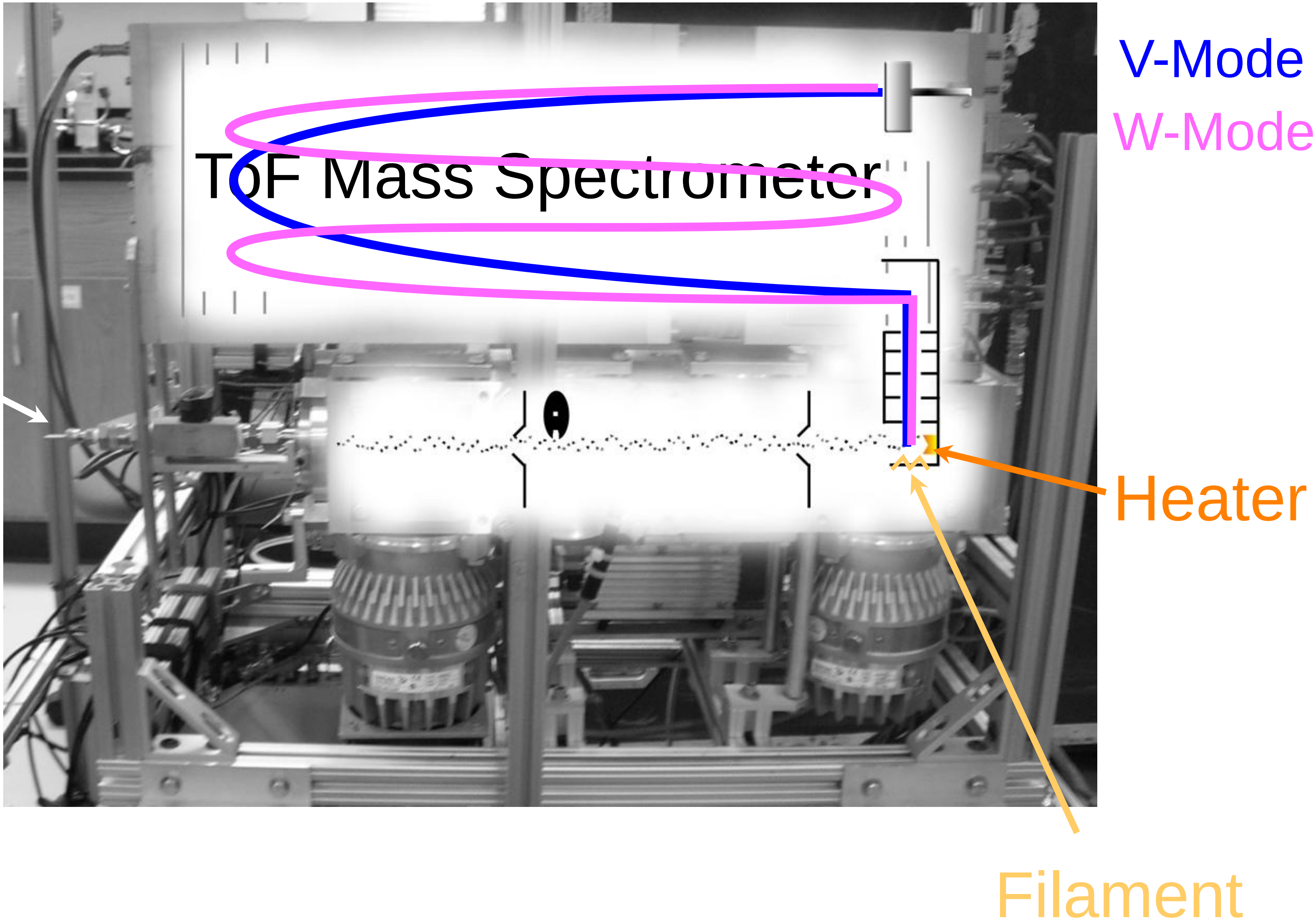
System Description: PTR-TOFMS



Identification:

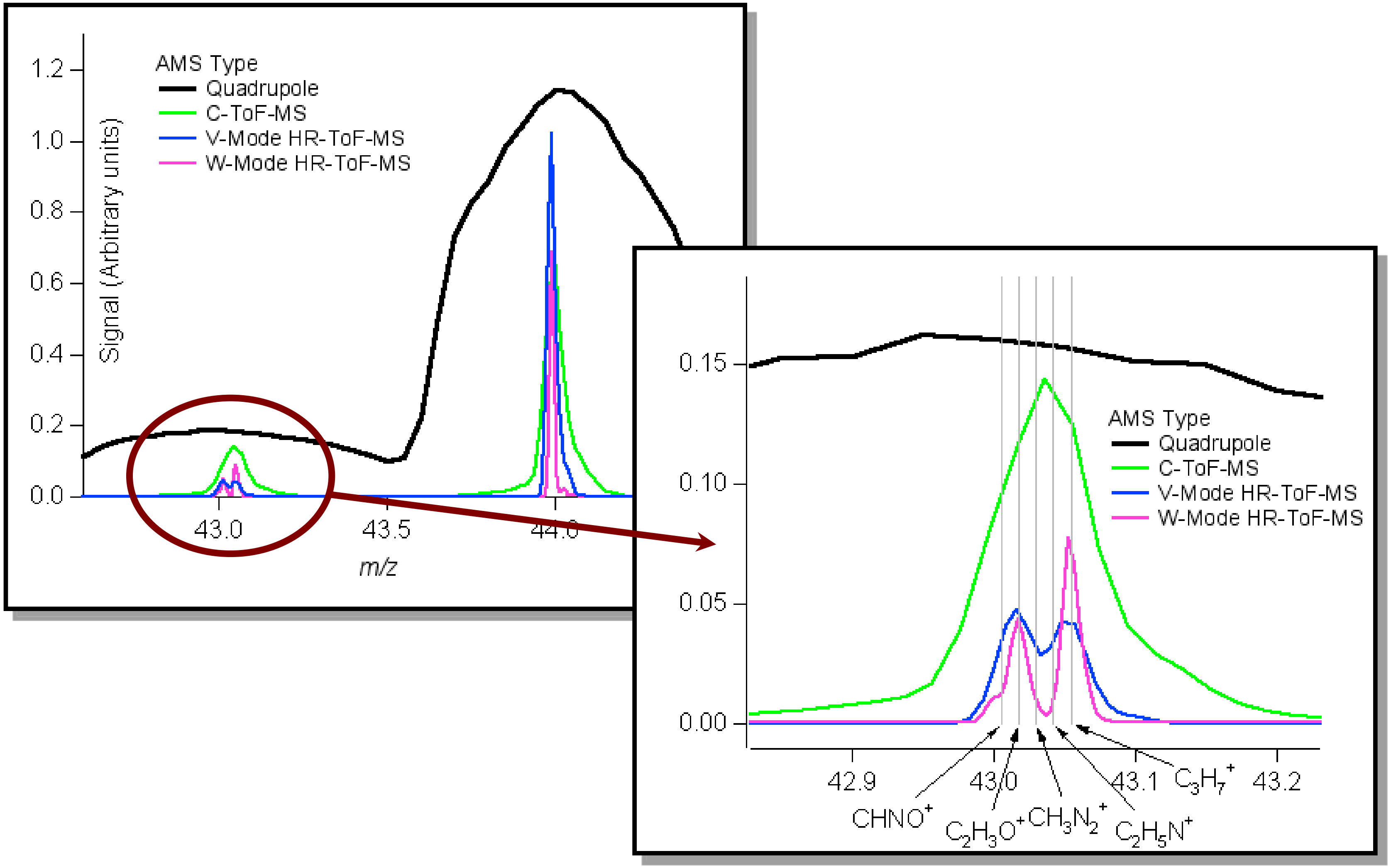
- Peak Separation
- Exact Mass Measurement
- Isotopic Ratio

HR-ToF-AMS



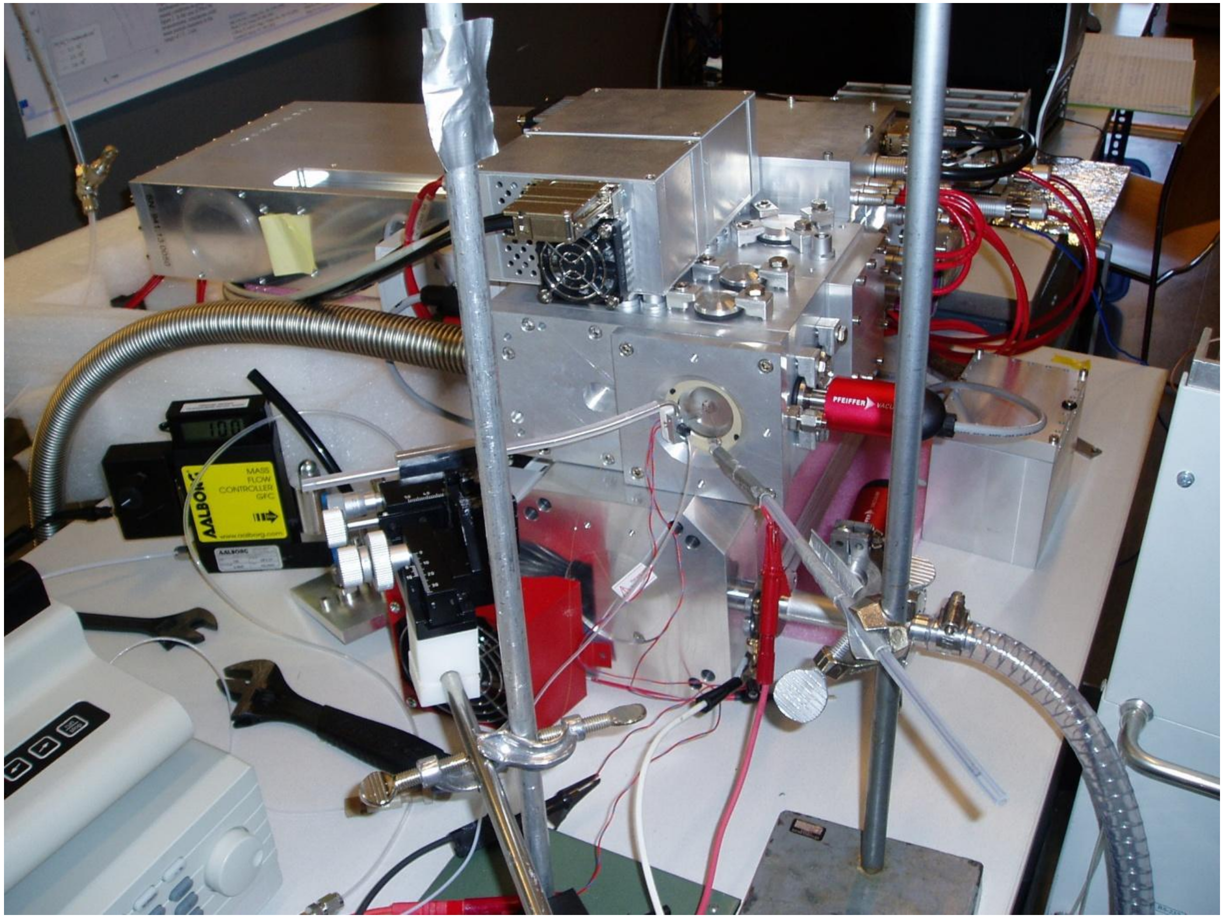
DeCarlo et al., Anal.Chem (2006)

High Resolution comparison

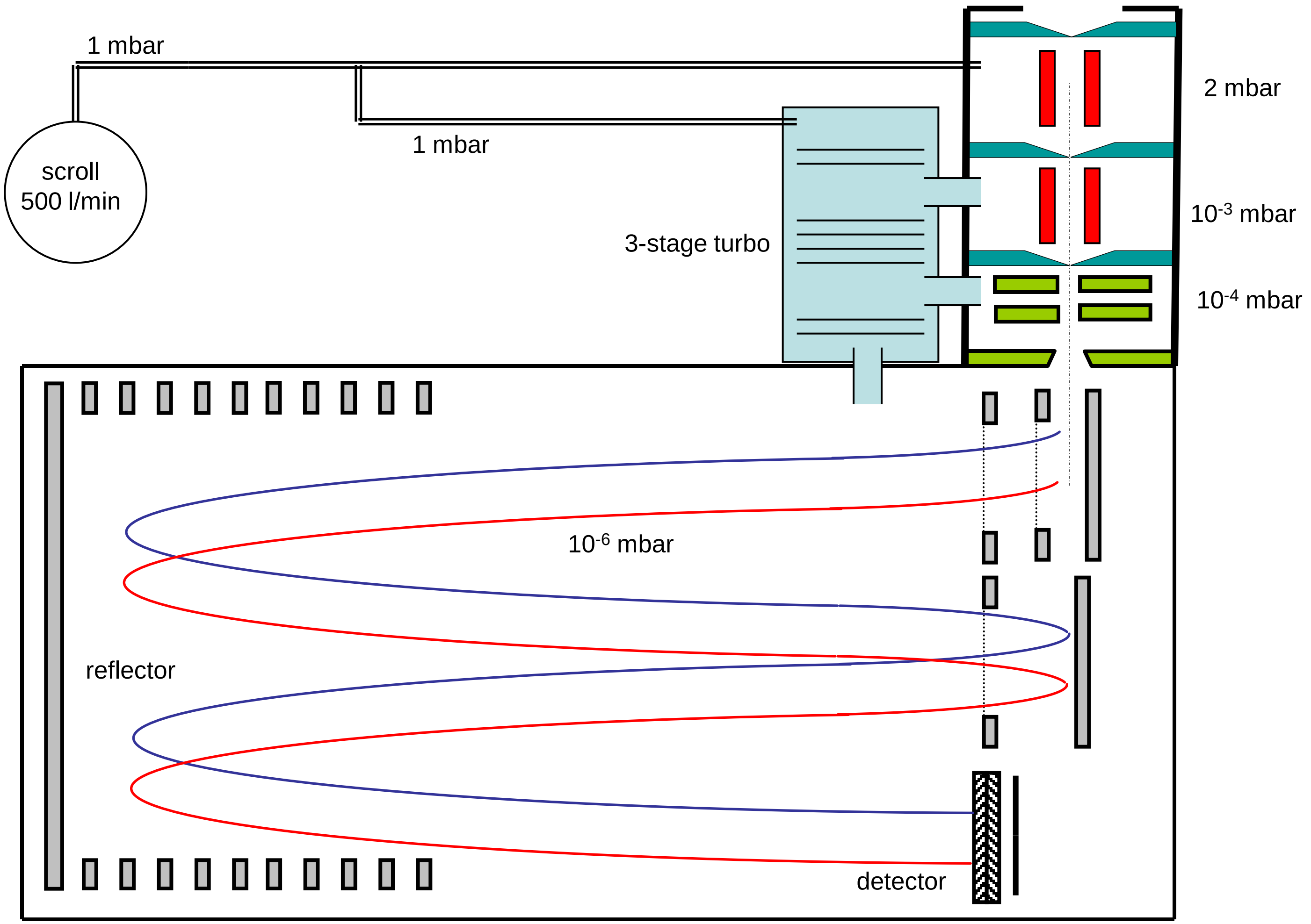


DeCarlo et al., Anal. Chem (2006)

Atmospheric Pressure Interface Time Of Flight (API-TOF) mass spectrometer

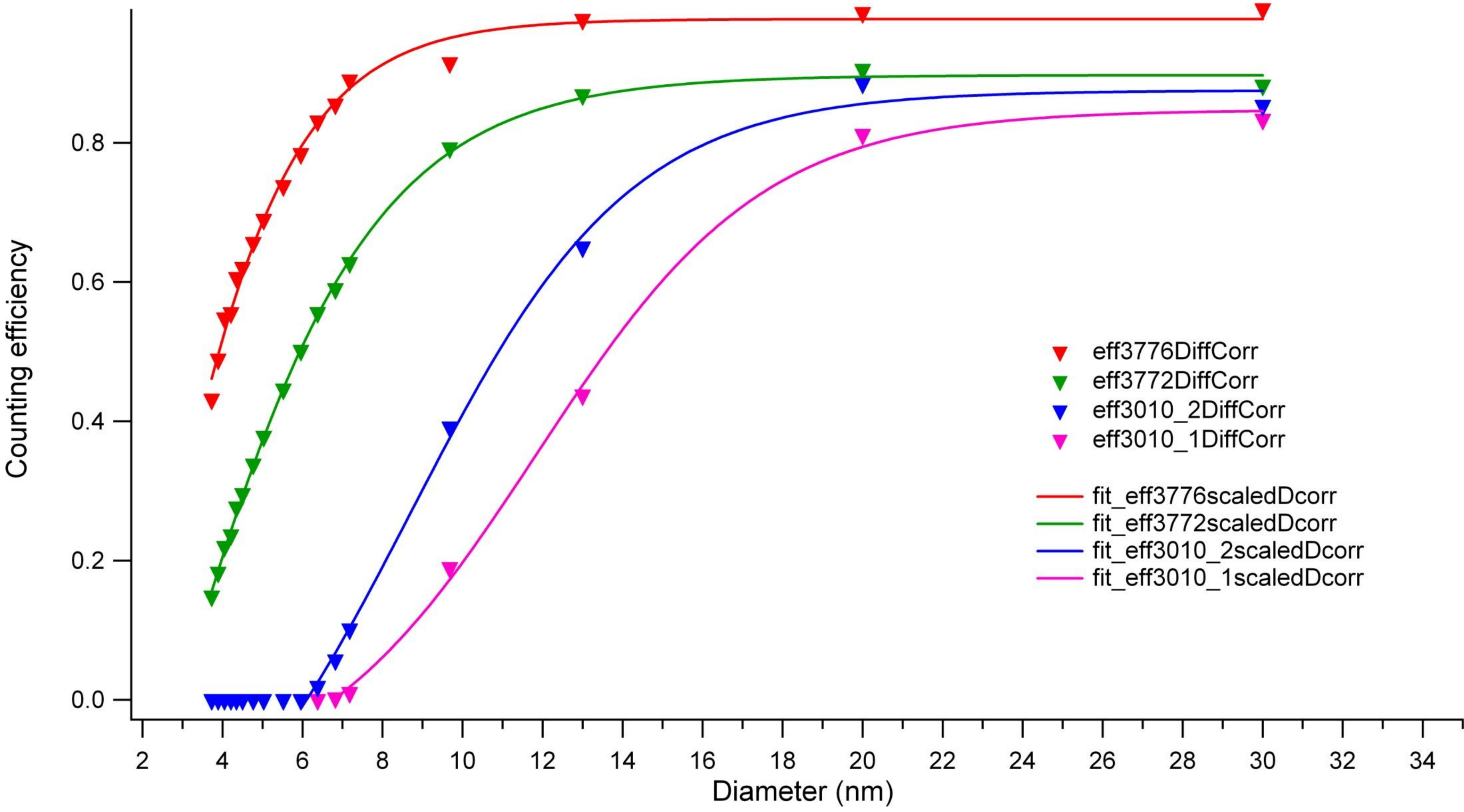


API-TOF scheme

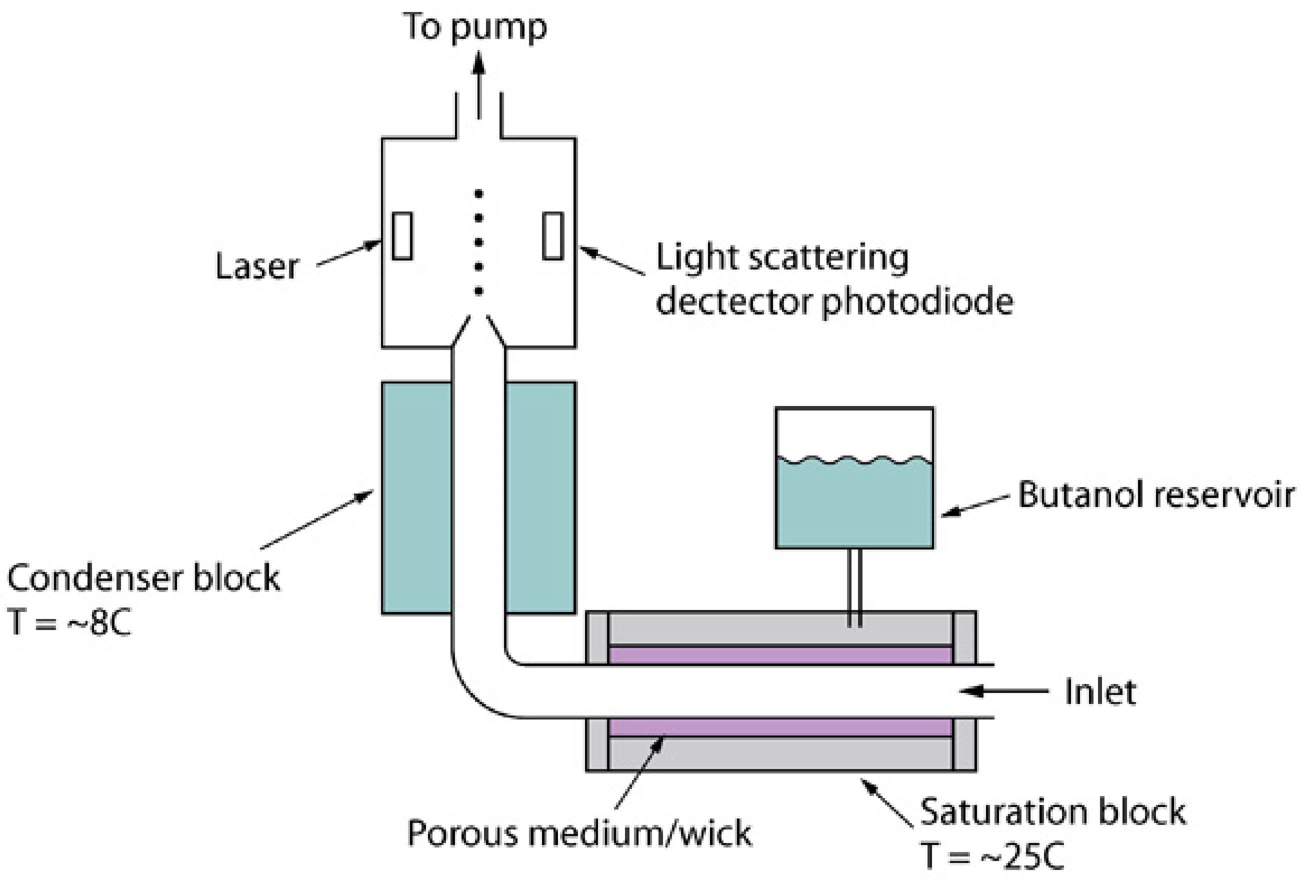


Condensation Particle Counter

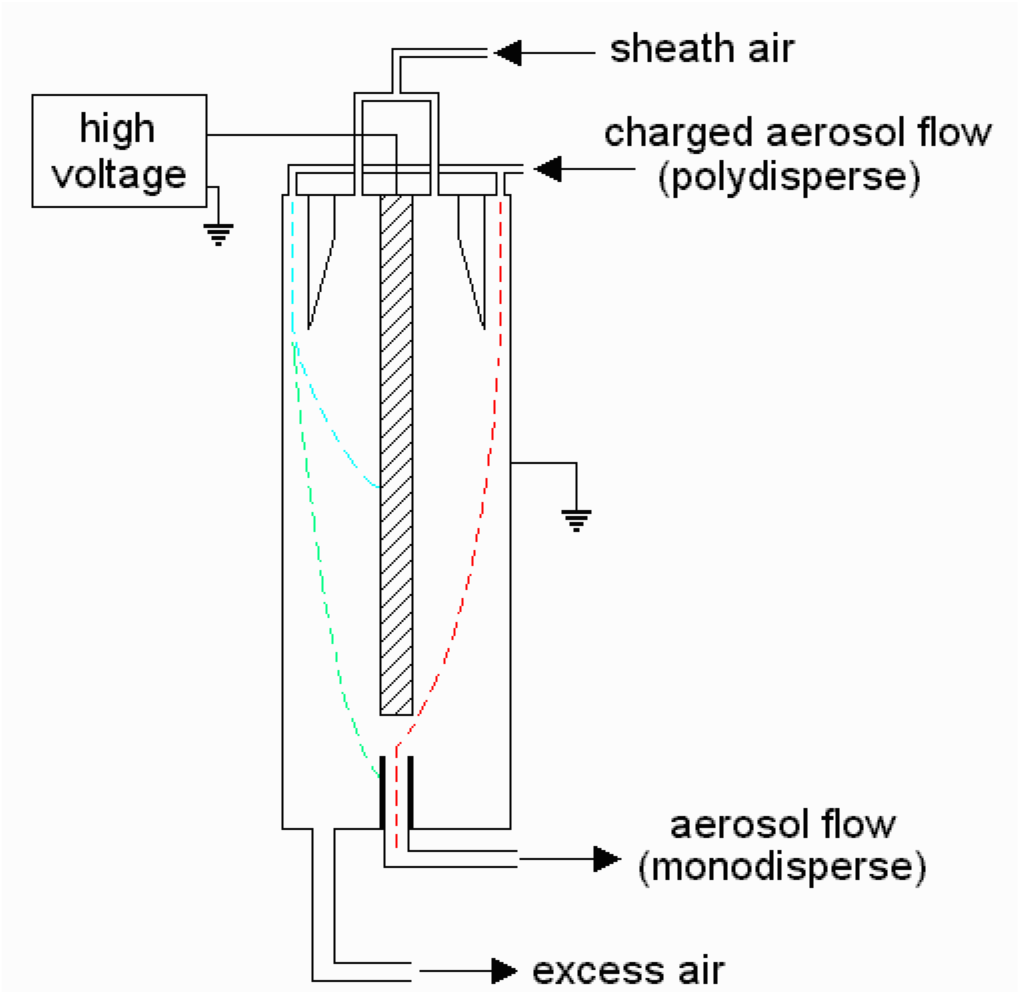
CPC detection efficiency



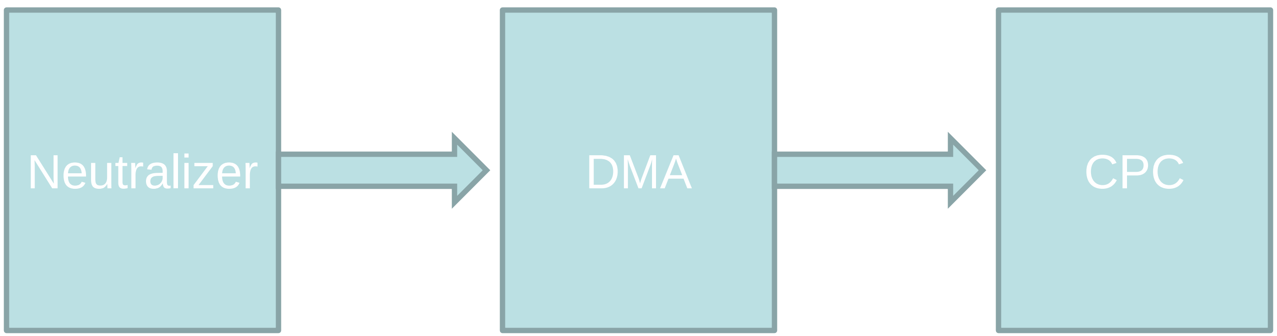
Buthanol CPC principle



Differential mobility analyser (DMA)



SMPS

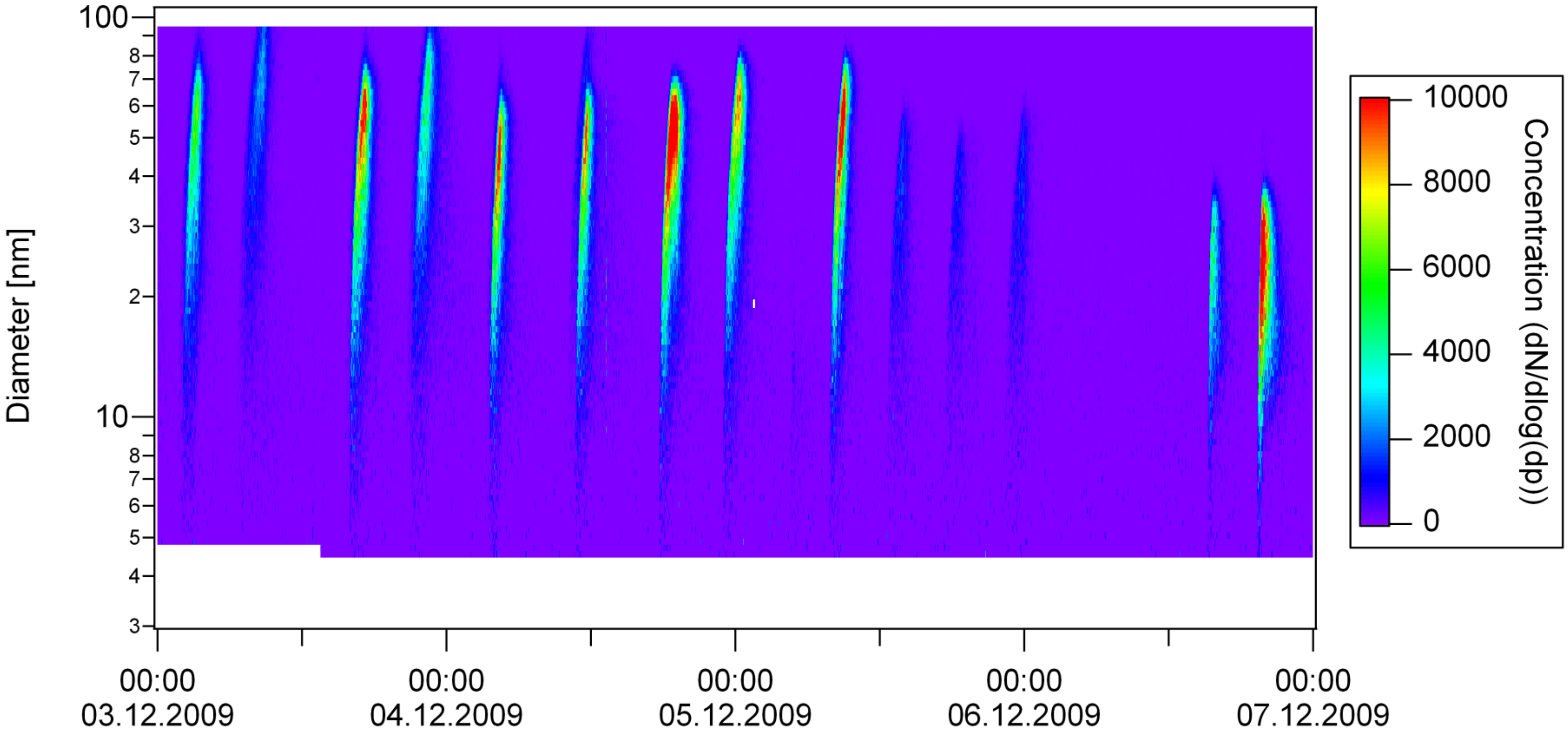


Known equilibrium charged of the particle

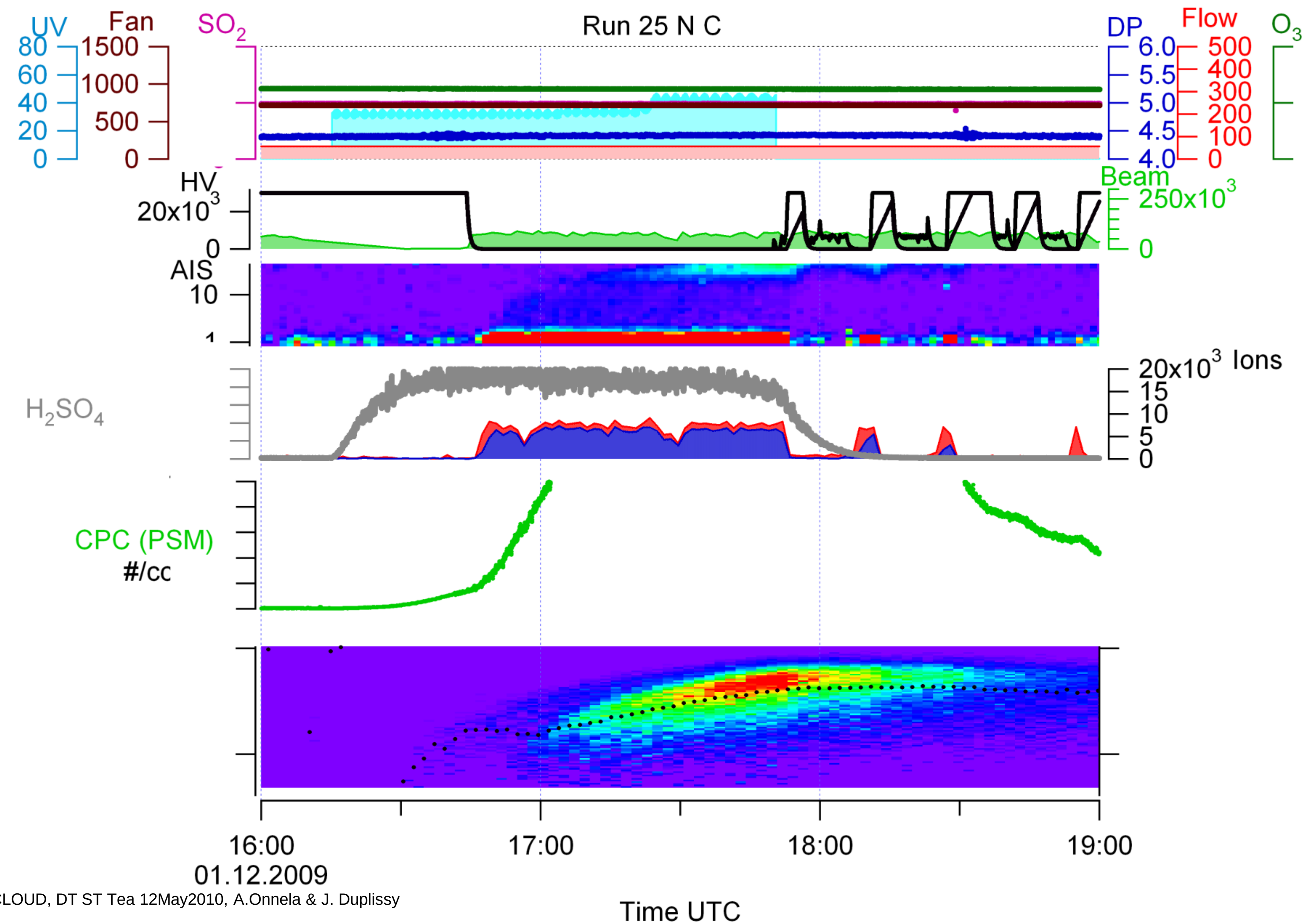
Select one size of the particle

Count the number of particle

Results 2009: fireworks at



Results 2009



Results

- Investigation of the nucleation rate depending on:
  - RH
  - Ions concentration
  - H_2SO_4 concentration

Future plan

- Near future (2010-2013)
  - Investigate the Temperature dependence
  - Investigate with other substance (organics)
  - Cloud droplet formation
  - Ice formation
- Far future (Beam not needed all the time)
  - Health effect
  - Other organics
  - Lower pressure experiment
  - Aerosol aging
  - Ice formation with different seed
  - Chemical evolution within cloud droplet
  - …


Eimear
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Linda
Siegfried
Alessandro
Francesco
Georgios
Jonathan
Jasper
Axel
Agnieszka
Oslo
Stockl
Tallinn
ESTONIA
Riga
LATVIA
Liepaja
Daugavpils
LITHUANIA
Vilnius
Dublin
Cork
Liverpool
Manchester
Birmingham
London
North Sea
Arhus
Copenhagen
Malmo
Baltic Sea
NETHERLANDS
Amsterdam
BELGIUM
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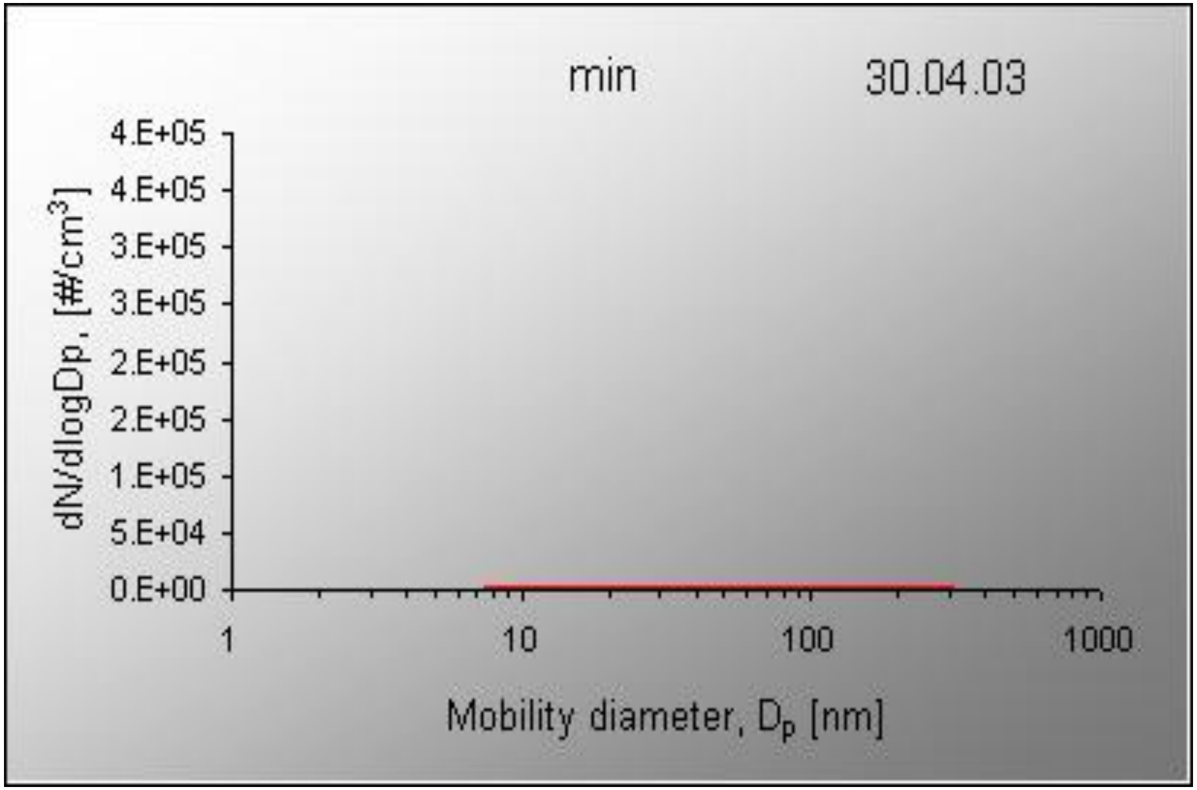
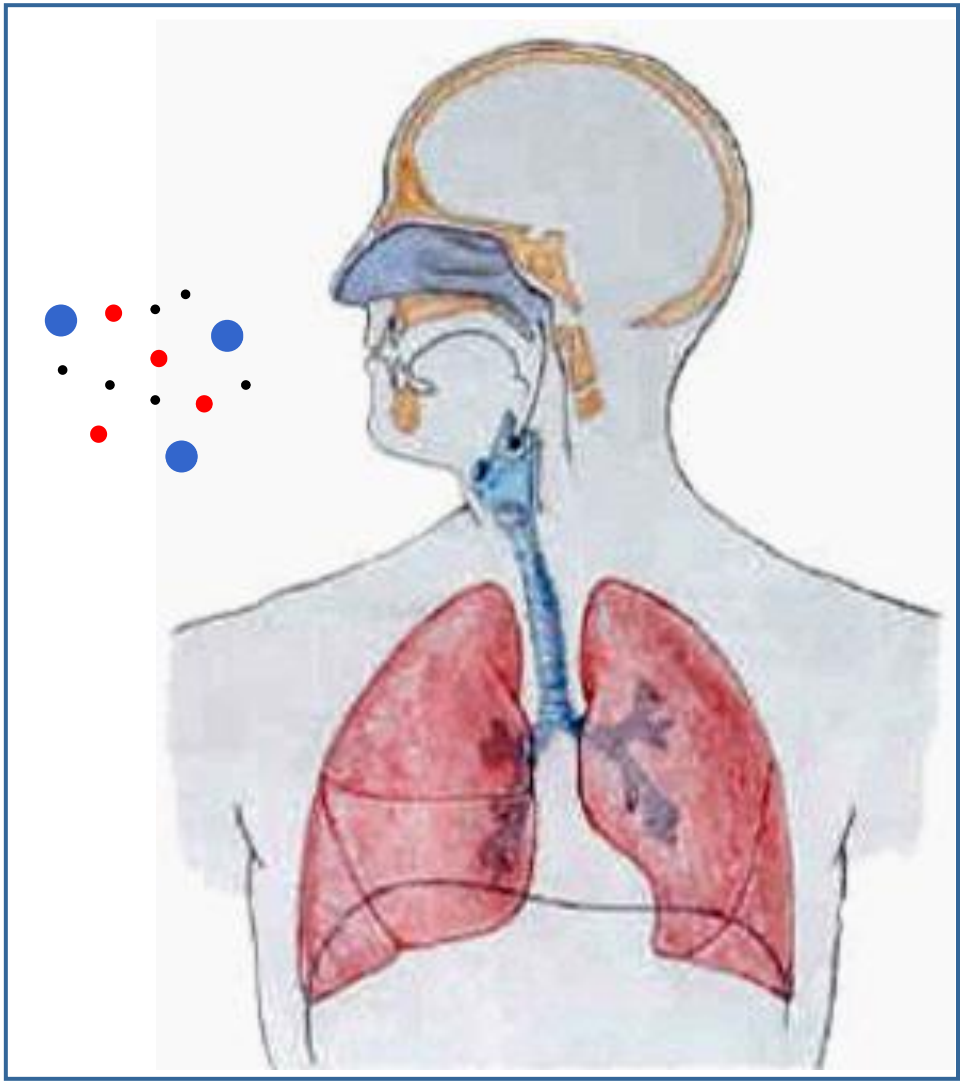
SAN MARINO
BOSNIA &
HERZE.
Florence
MONACO
ITALY
Sarajevo
Podgorica

Backup slide

Results: Nucleation event measured with a SMPS



Aerosol health effects



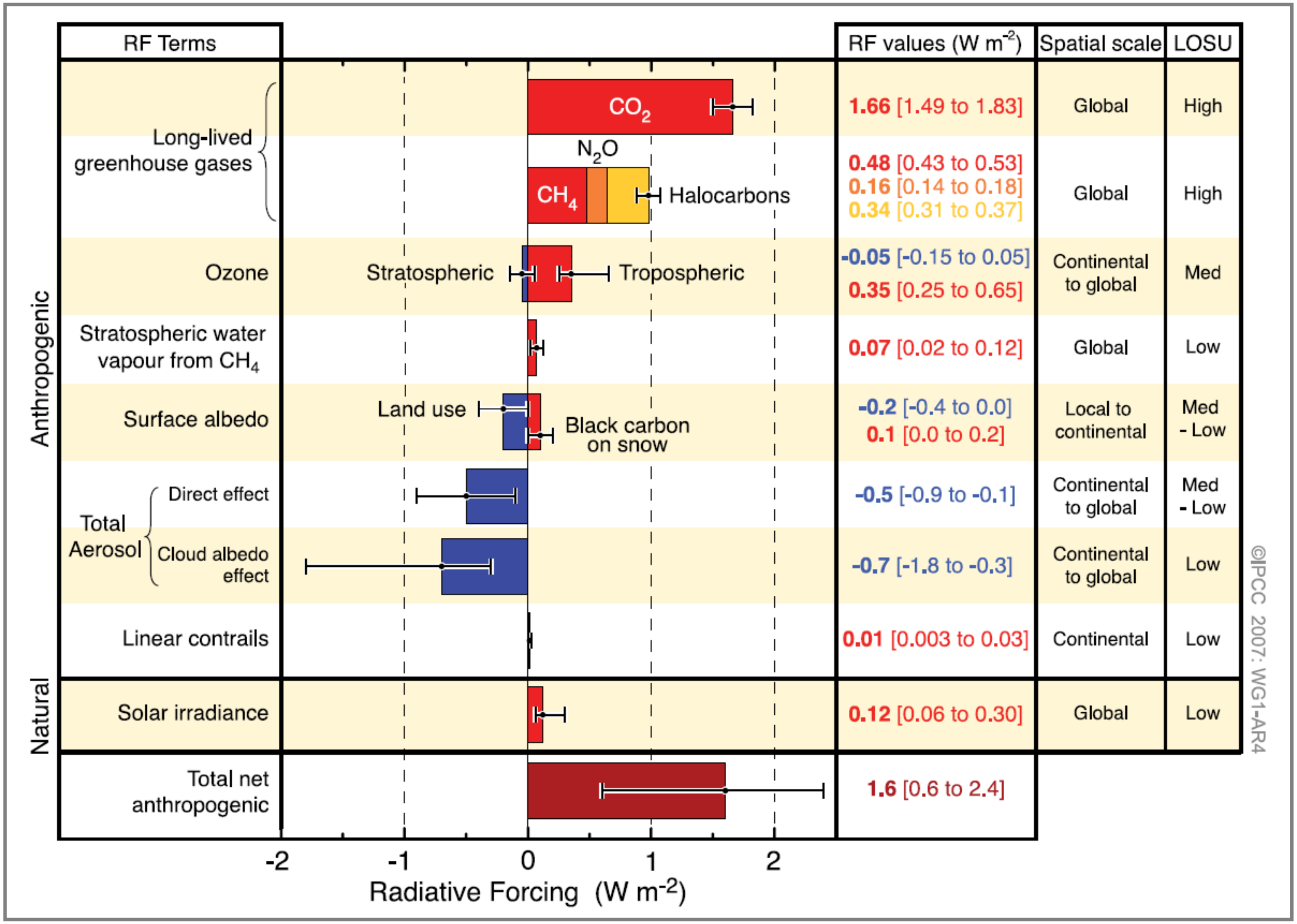
Importance of aerosol particle size

- D > 2.5μm
- D < 1-2.5μm
- D < 1μm

Importance of chemical composition of the soluble fraction

Penetration of toxic components and irritation of the breathing system

The global mean radiative forcing of the climate system



IPCC 4th assessment report, 2007

N.A.I.S.

Neutral Cluster and Air Ion Spectrometer

Mobility analyzer: DMA + electrometers

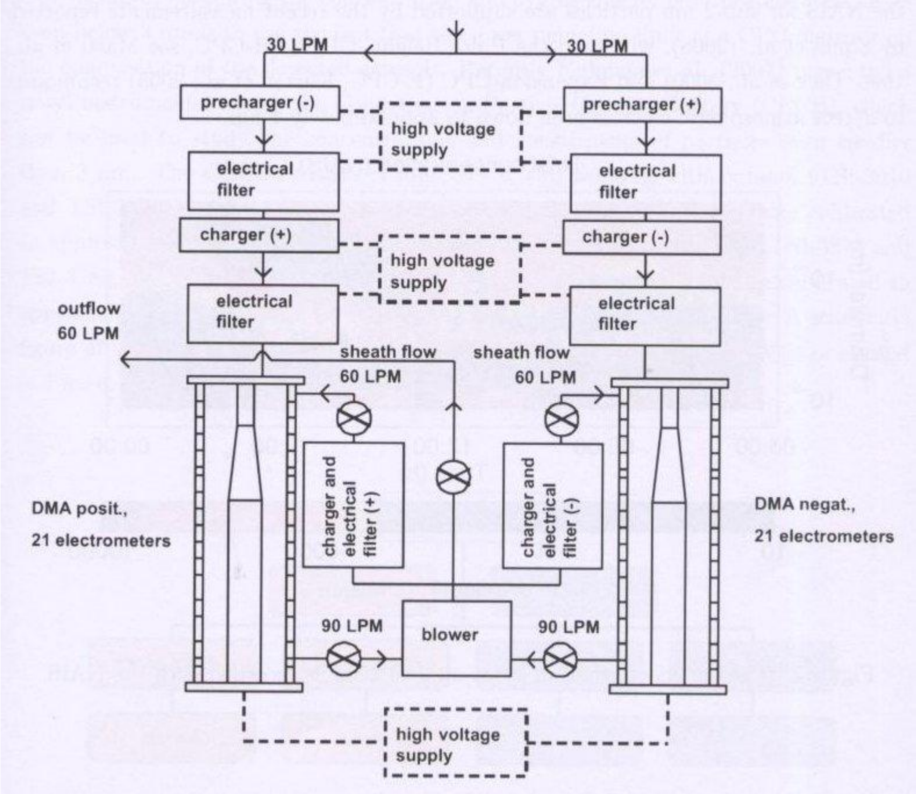
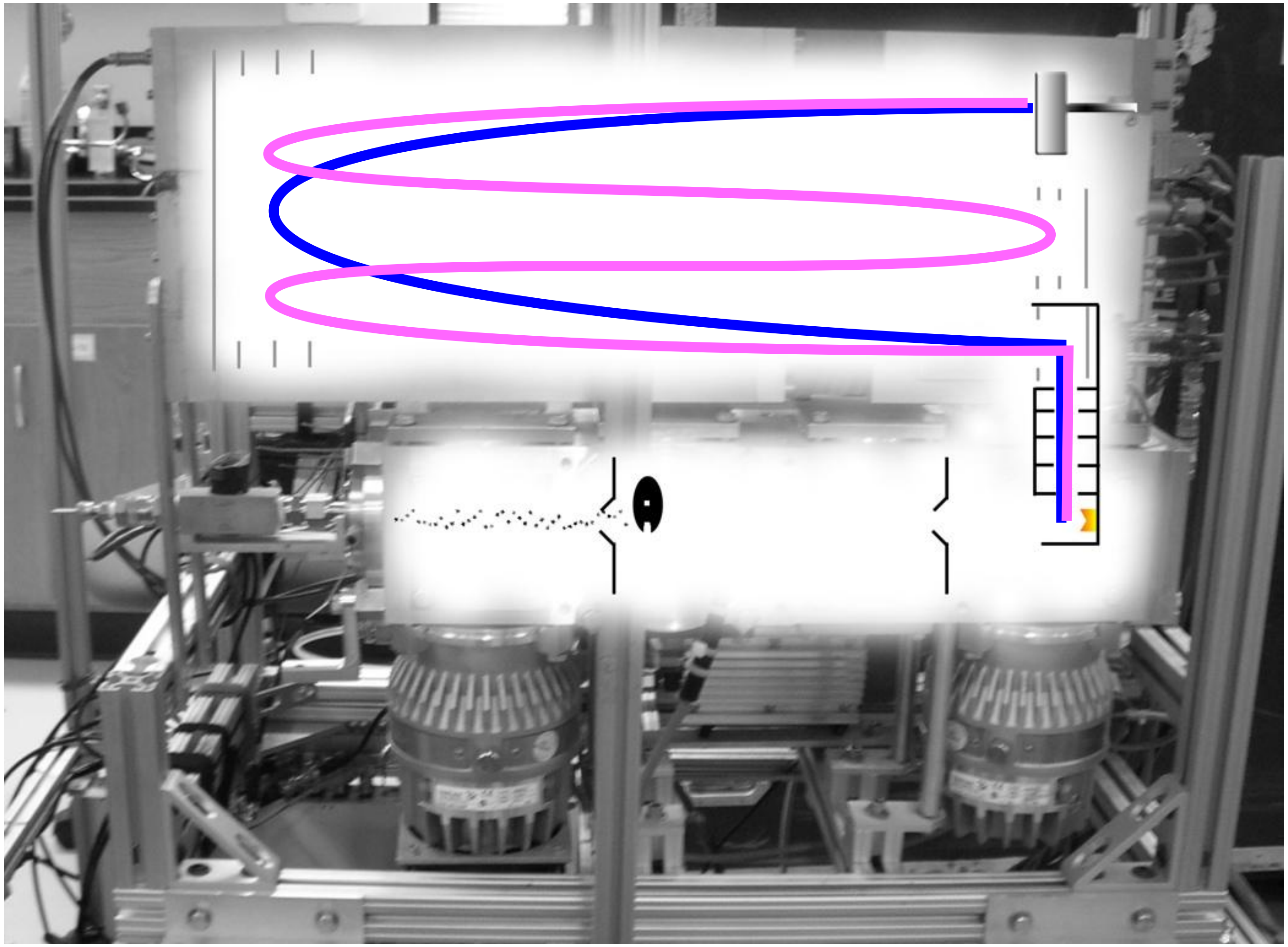


Figure 4: A schematic figure of the Neutral Cluster and Air Ion Spectrometer (NAIS, courtesy of Ms. Hanna Manninen and Dr. Aadu Mirme).

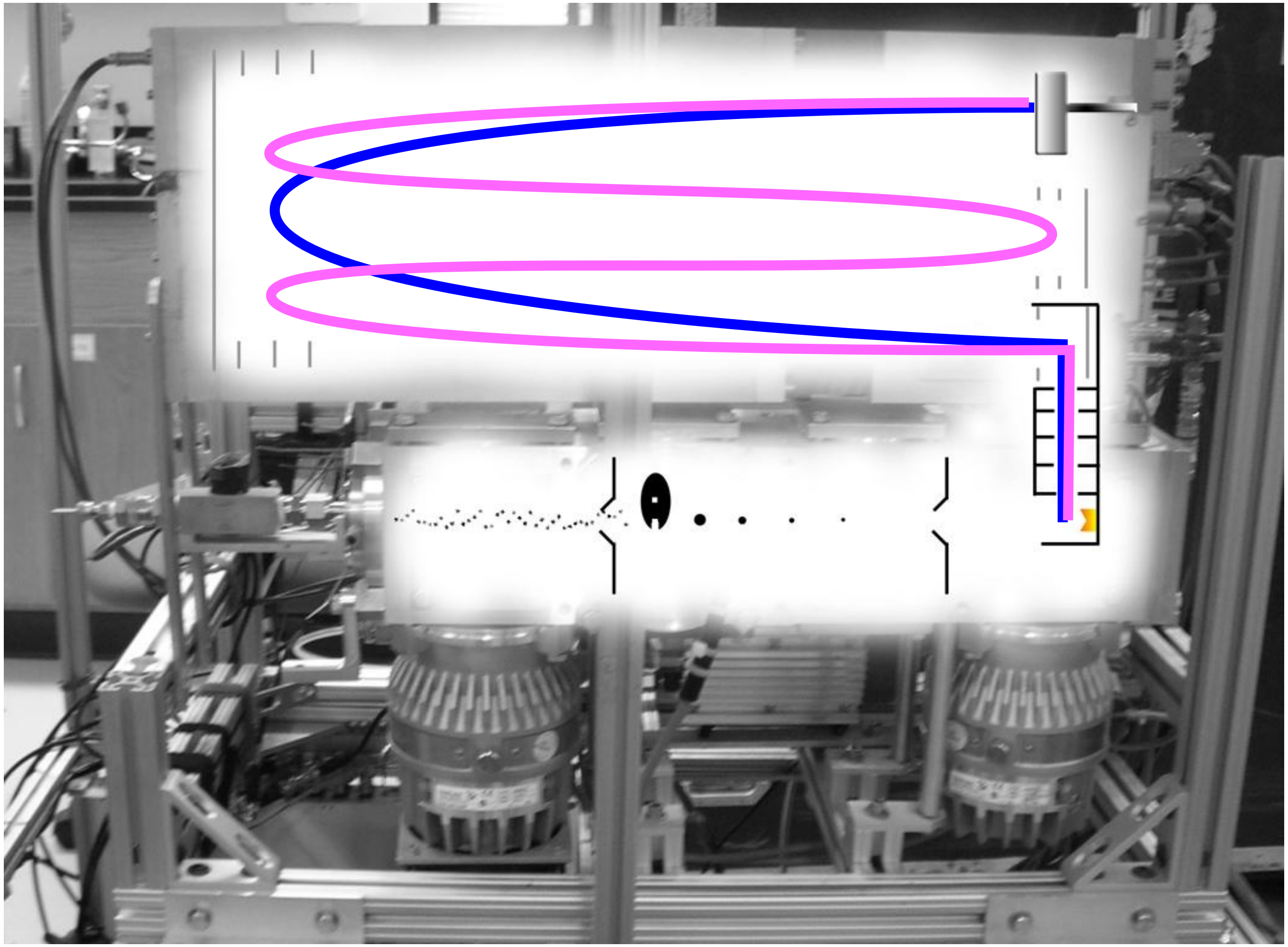
Aerosol Mass Spectrometer



V-Mode
W-Mode

- Particle Beam Blocked

Aerosol Mass Spectrometer



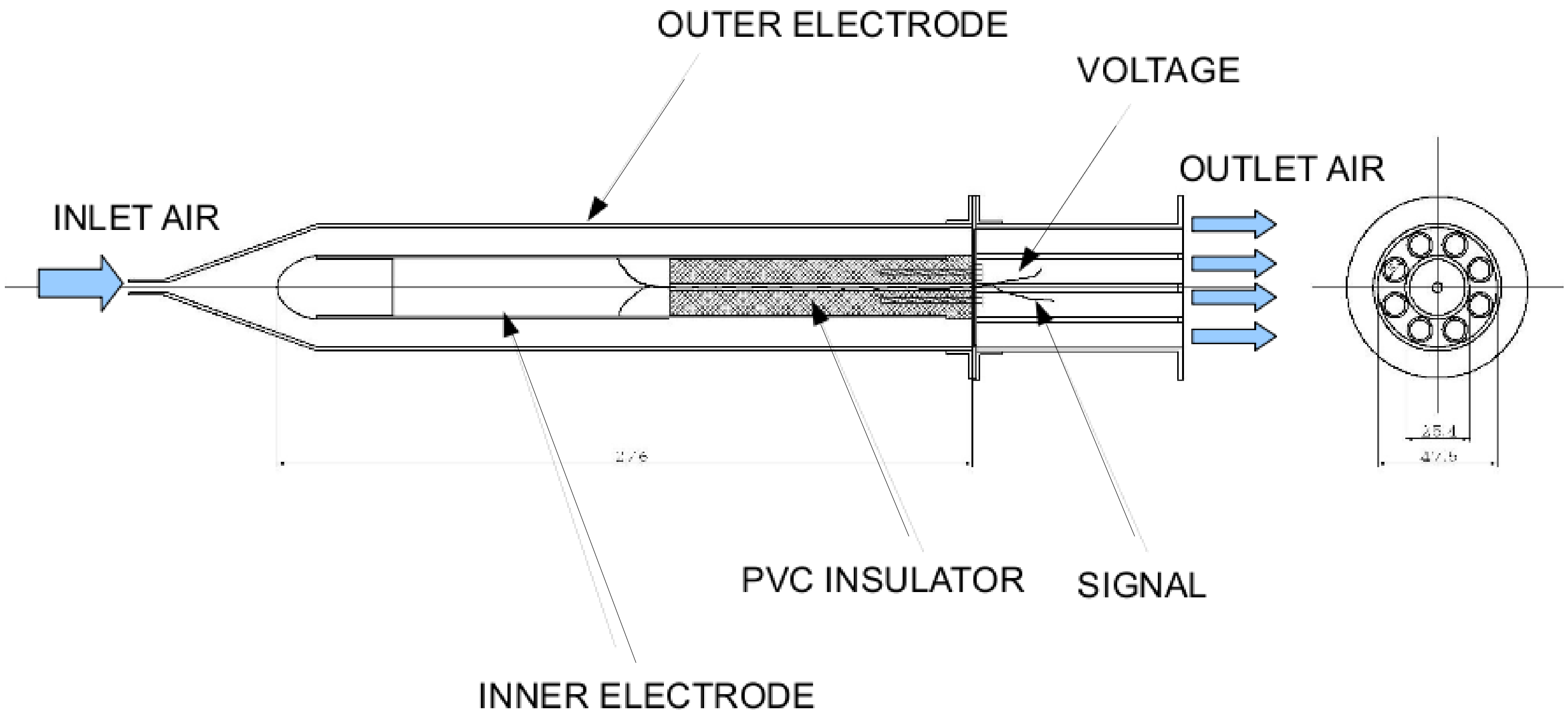
V-Mode

W-Mode

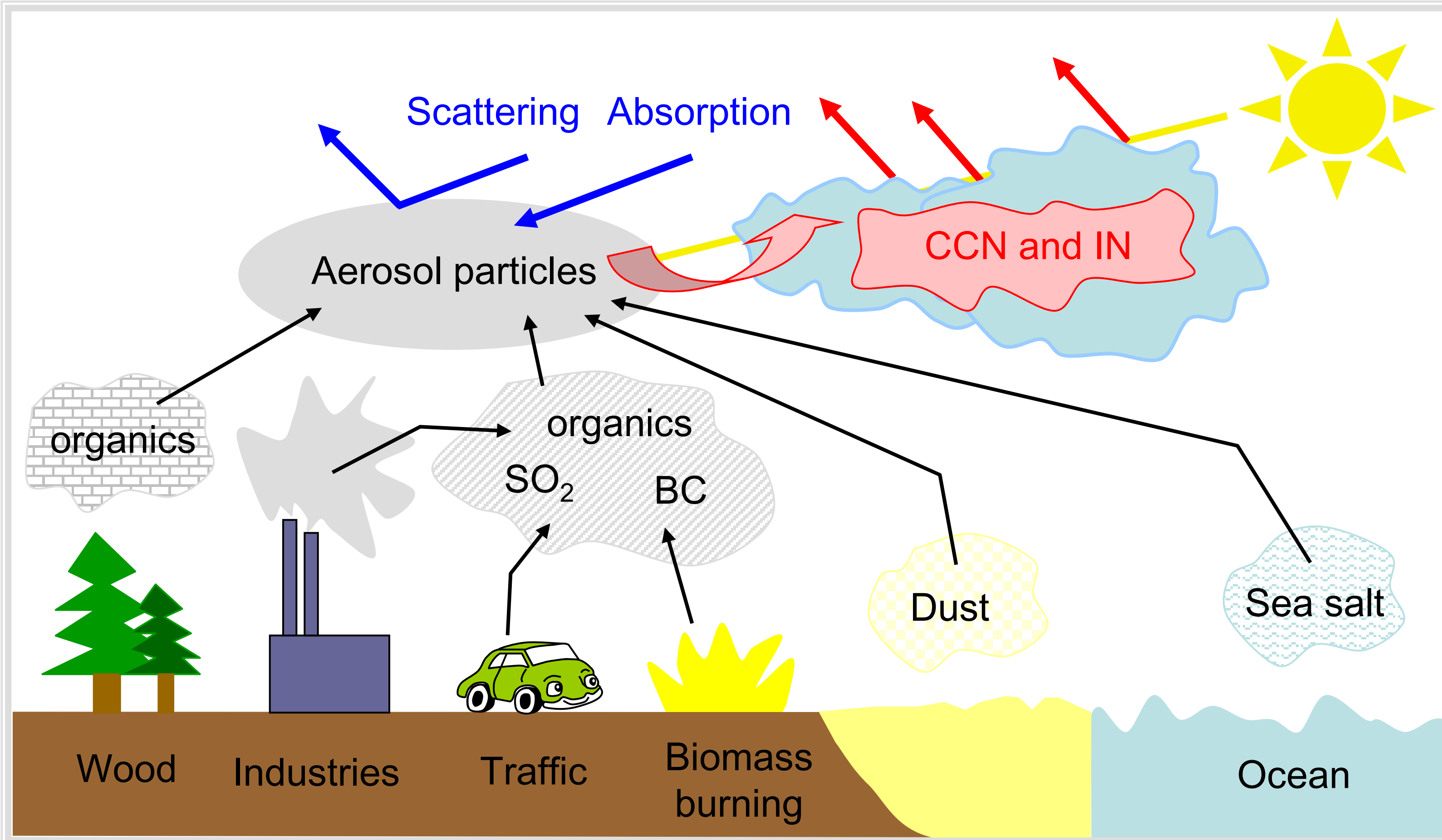
- Particle Beam Chopped

GERDIEN

Total ion counter

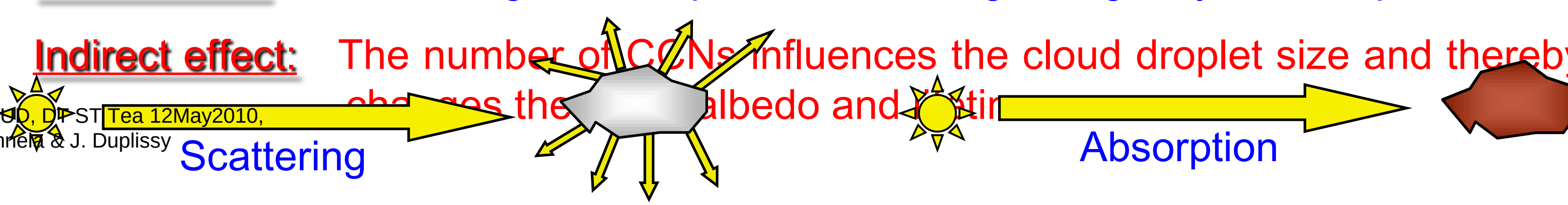


Aerosol climate effects



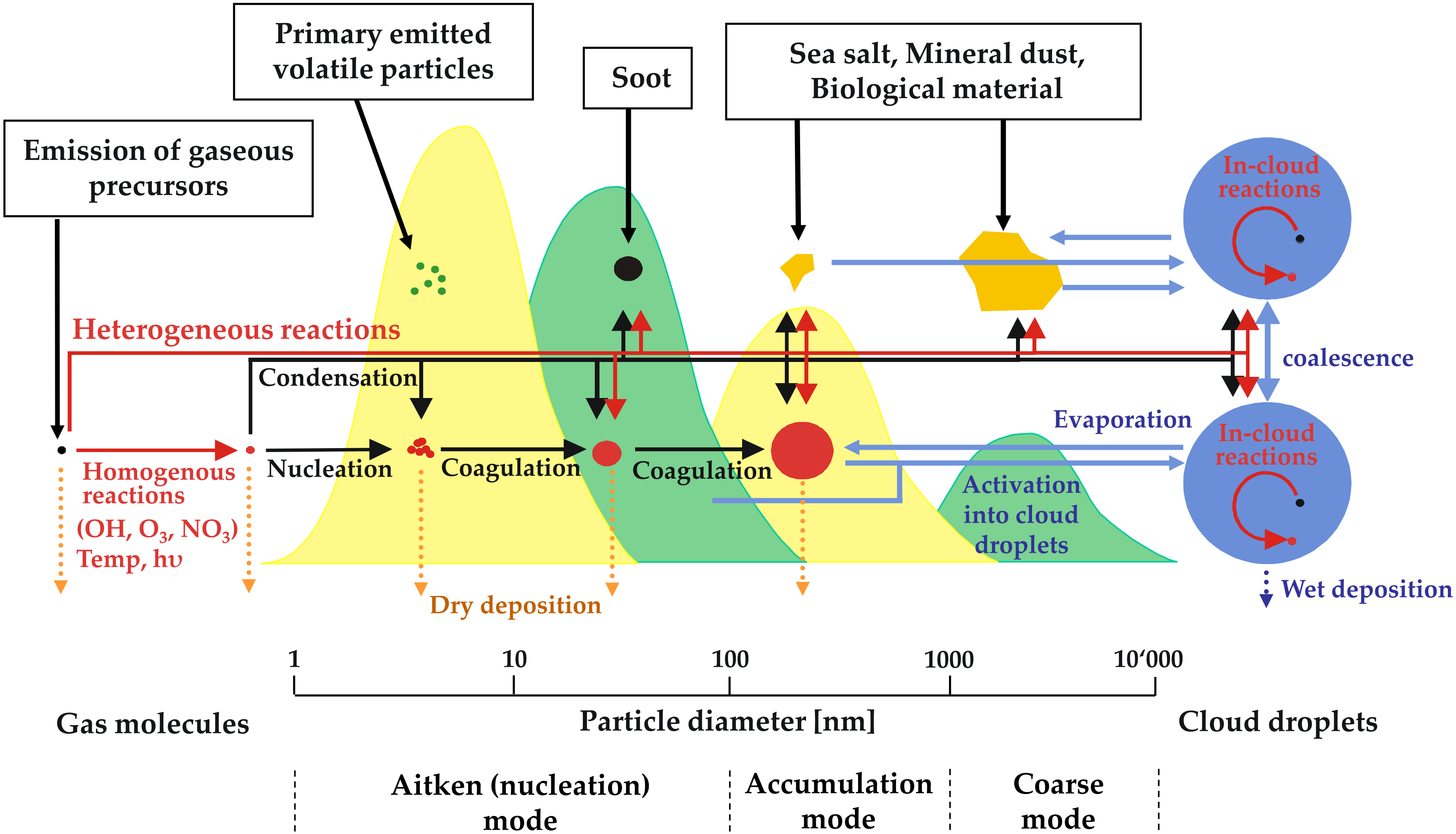
Direct effect: Scattering or absorption of incoming sunlight by aerosol particles

Indirect effect: The number of CCNs influences the cloud droplet size and thereby changes the … albedo and …

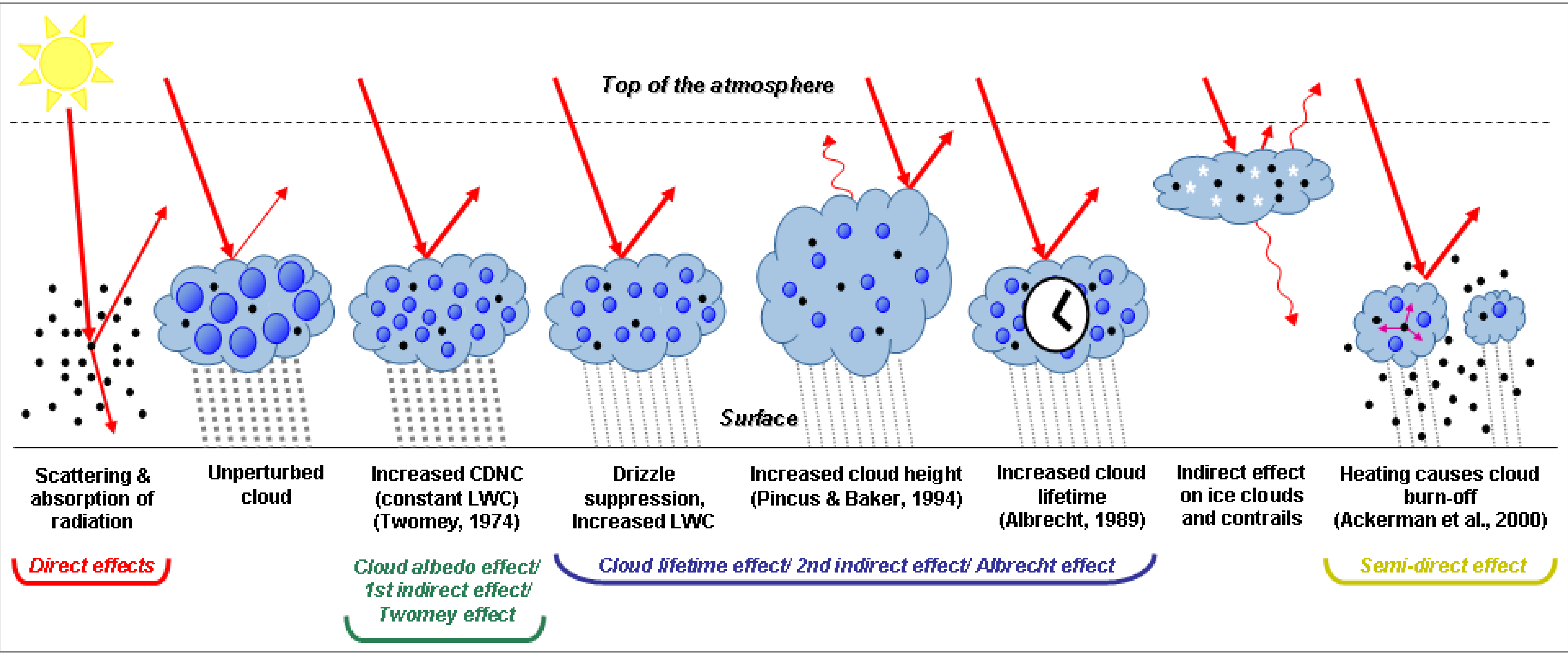


Aerosol Sources

Raes et al., Atmos Env, 34 (25), 4215-4240, 2000



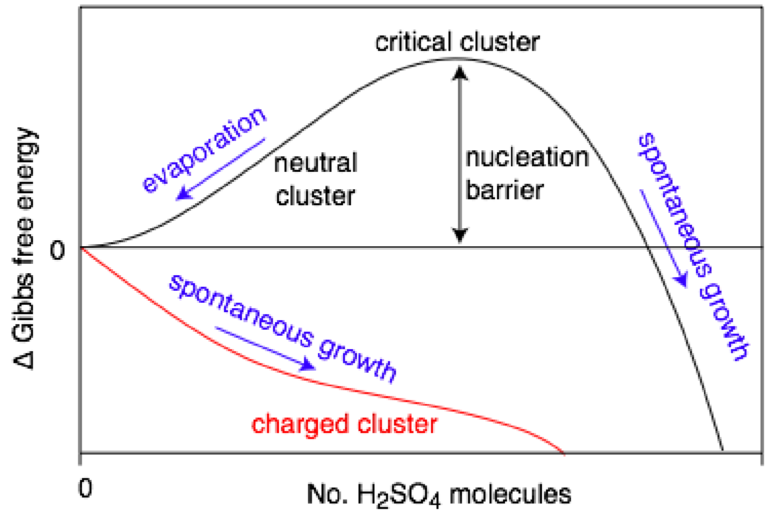
Various radiative mechanisms

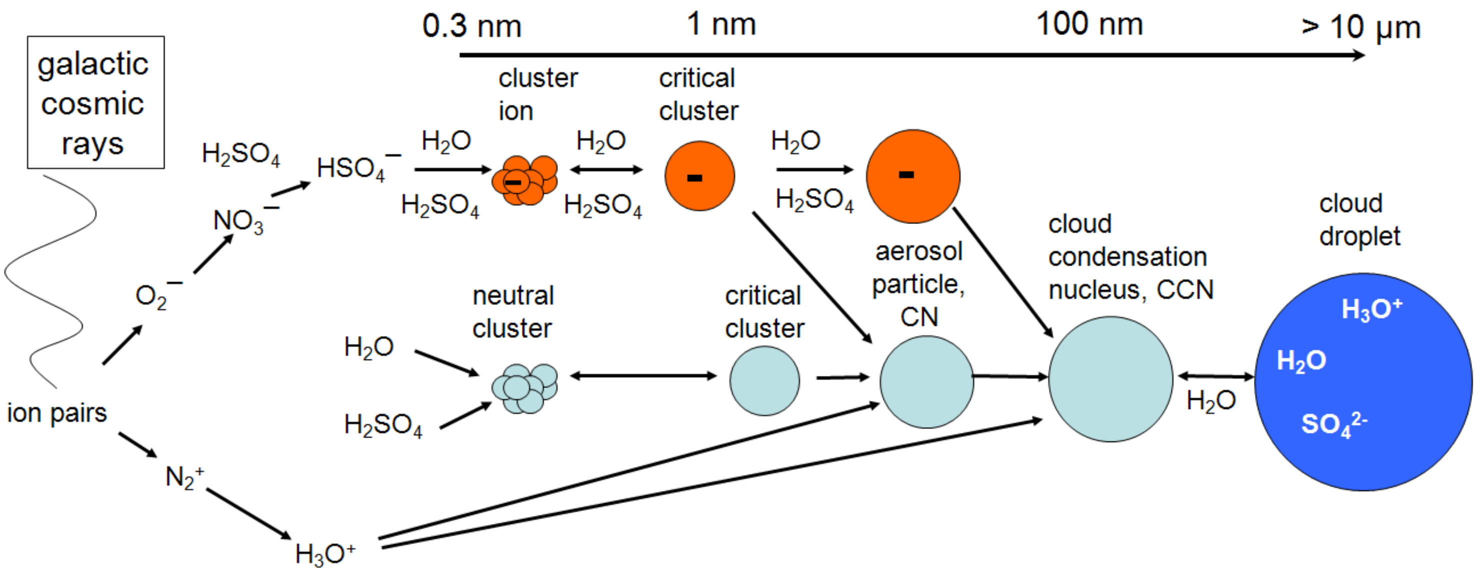


IPCC 4th assessment report, 2007

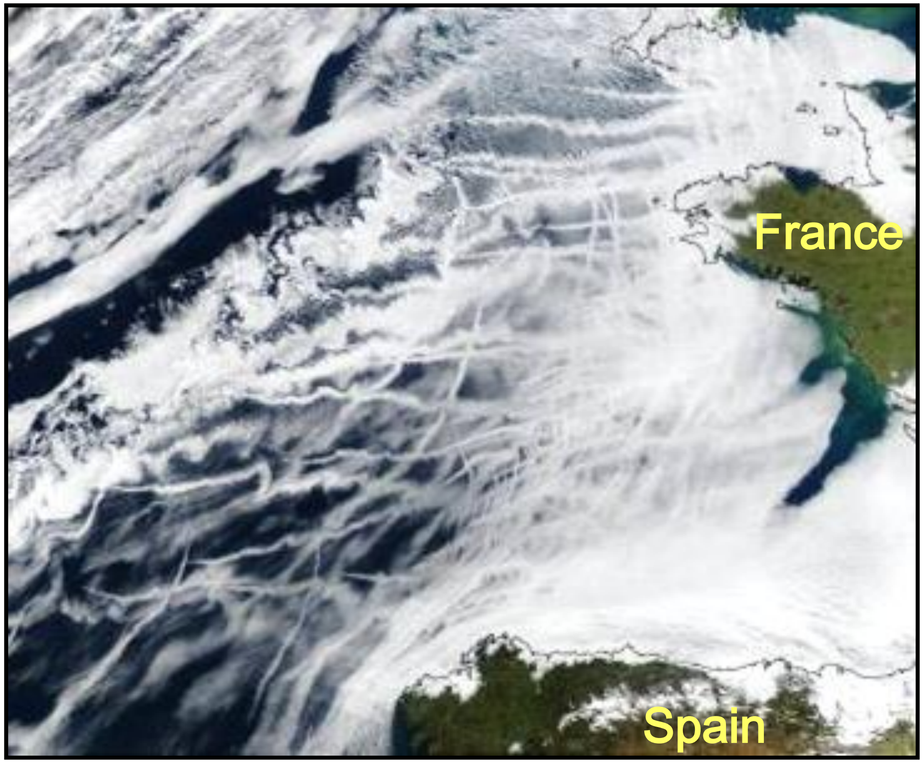
Aerosols from gas-to-particle conversion / Cosmic rays

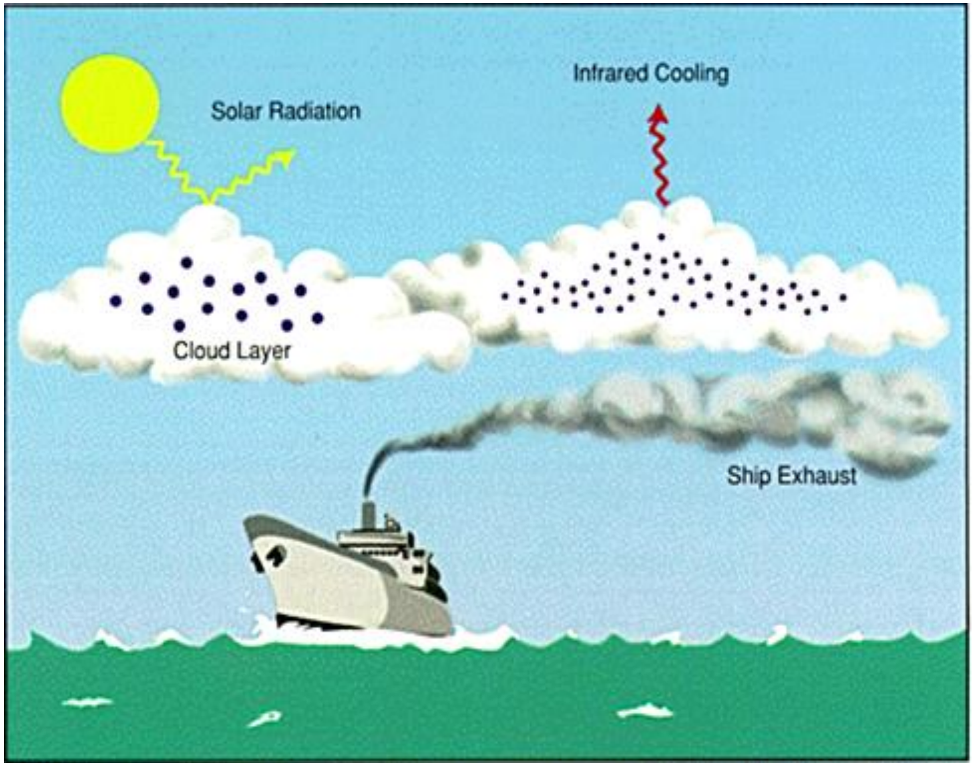
- Trace condensable vapour → CN → CCN
- Contributing vapours and nucleation rates poorly known
- H_2SO_4 is thought to be the primary condensable vapour in atmosphere (sub ppt)
- Ion-induced nucleation pathway is energetically favoured but limited by the ion production rate and ion lifetime
- *Candidate mechanism for solar-climate variability by solar wind modulation of galactic cosmic rays*
  - ***Studied by CLOUD***





Indirect effect of carbonaceous particles: Ship tracks

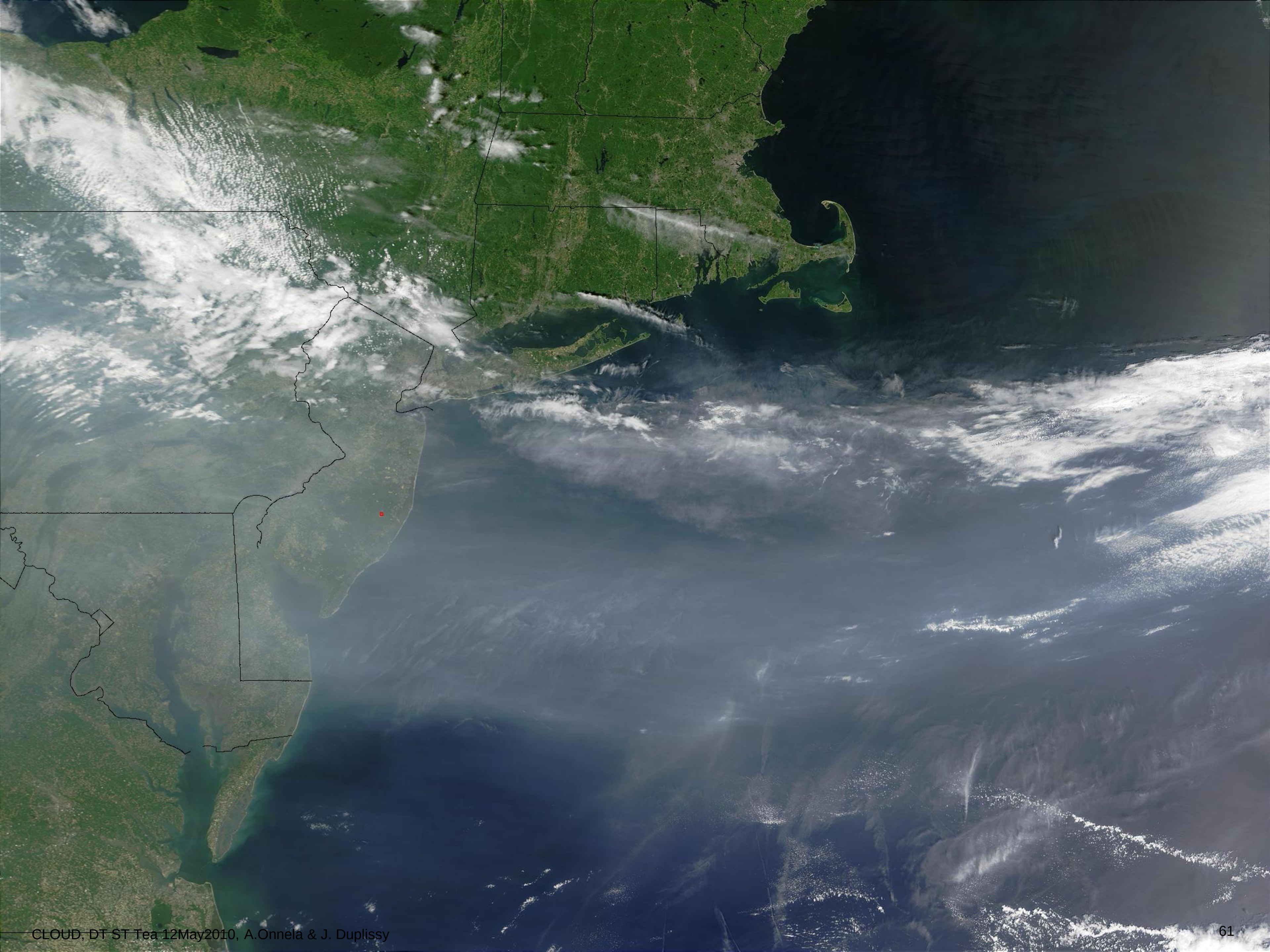


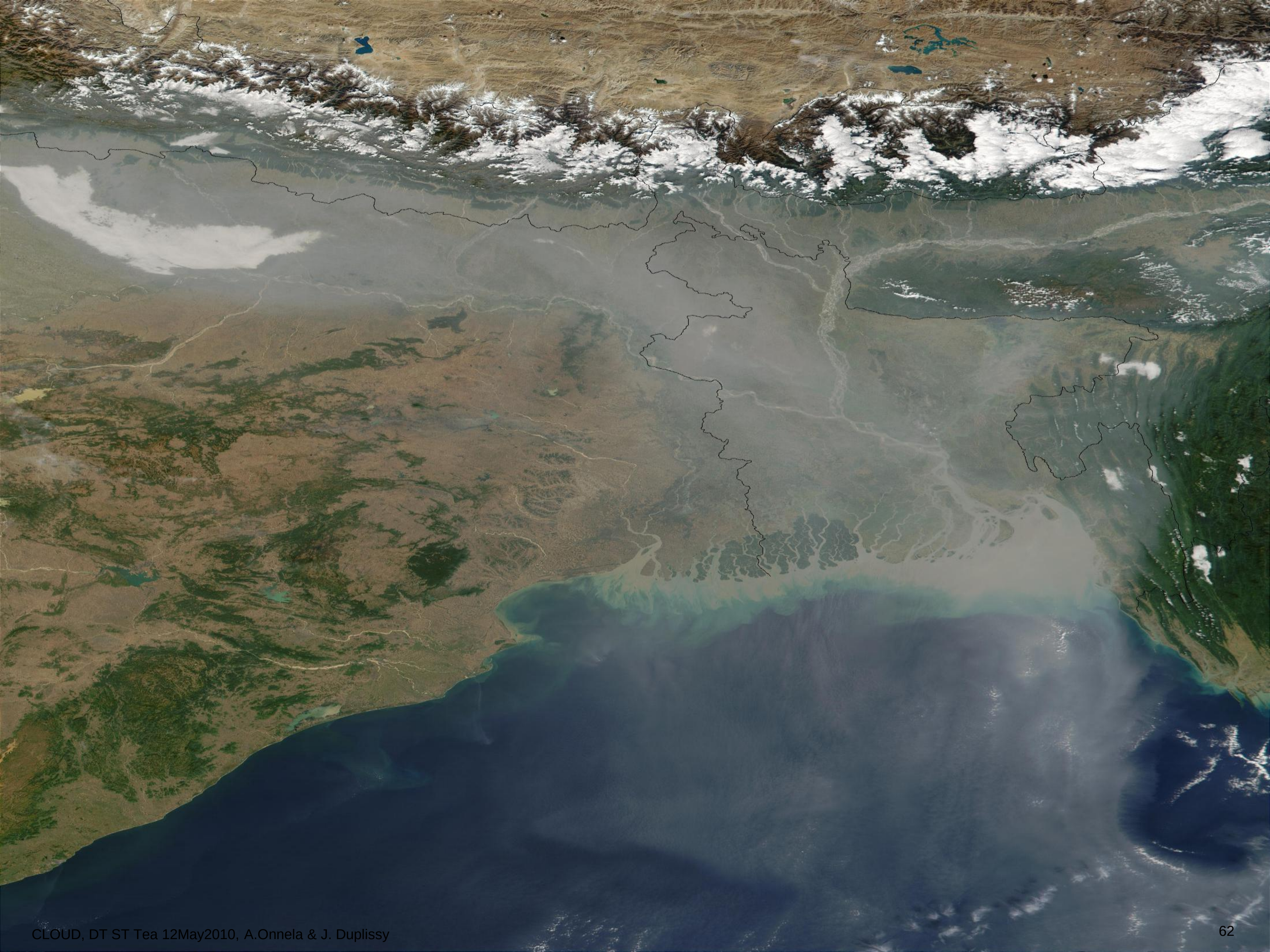


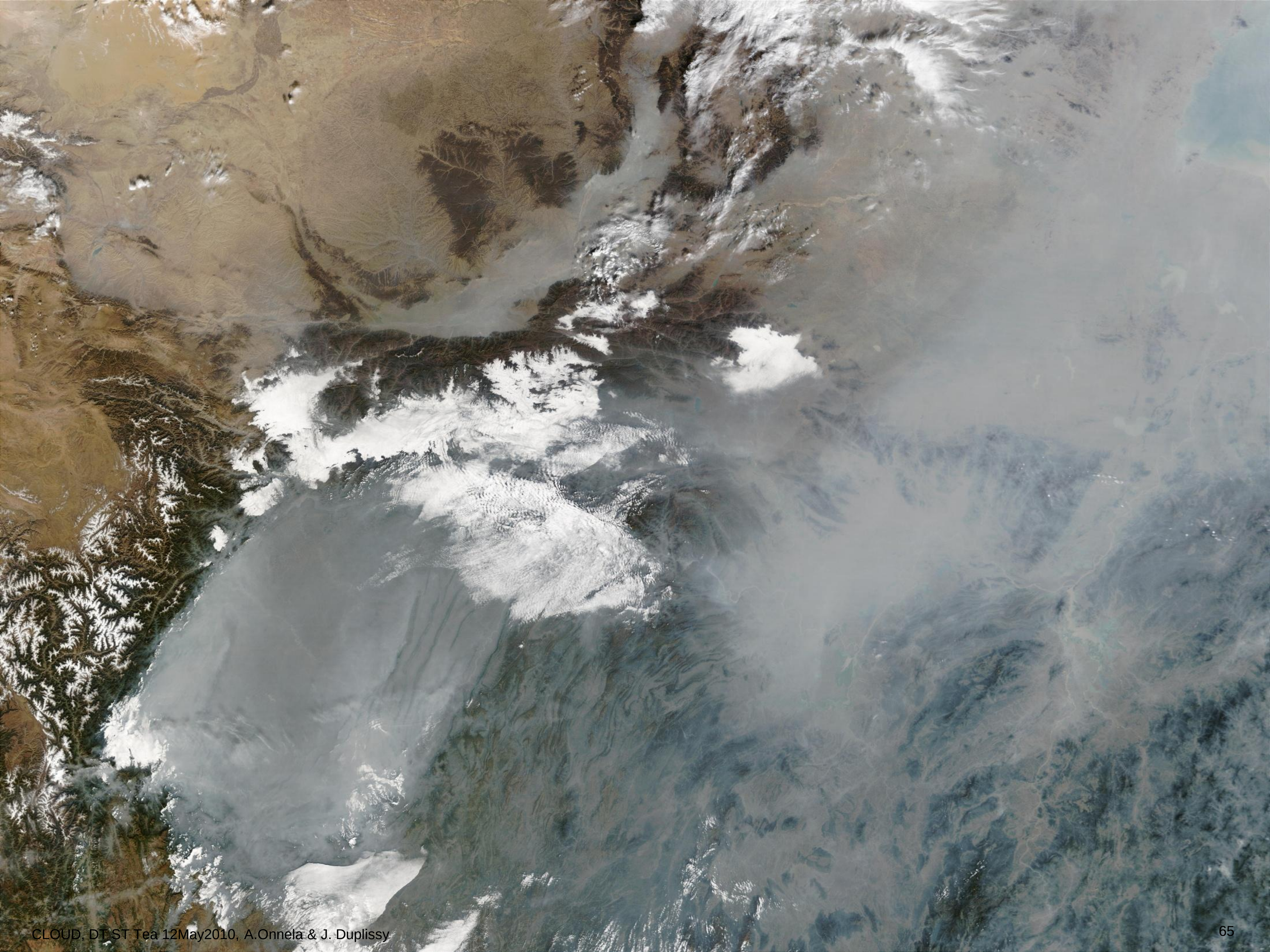
Ship tracks on the East Atlantic

Aerosol particles emitted by ships (soot particles with a high sulfur content) act as CCN and form clouds and enhance cloud reflectivity

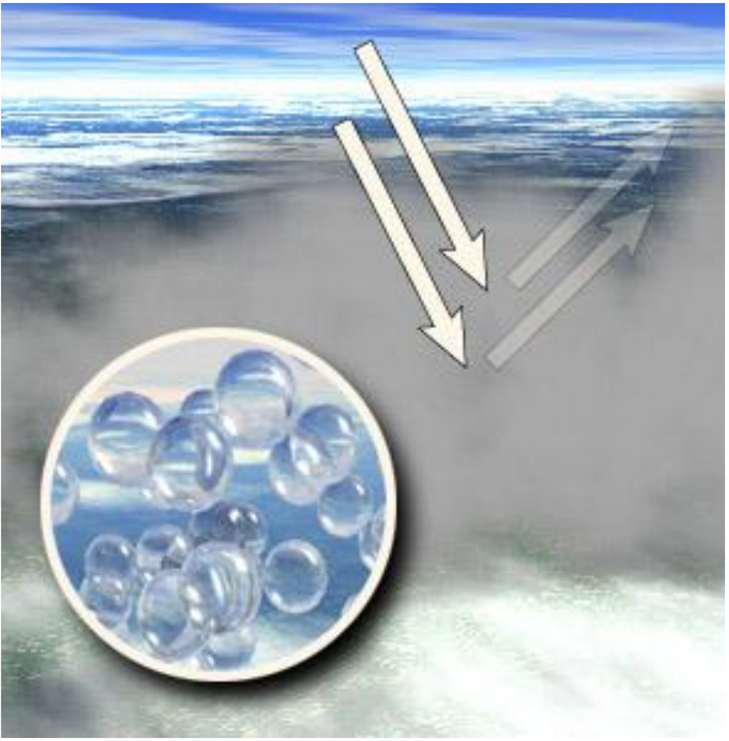
http://visibleearth.nasa.gov/







Indirect aerosol effect



Large droplets

→ Weak reflection

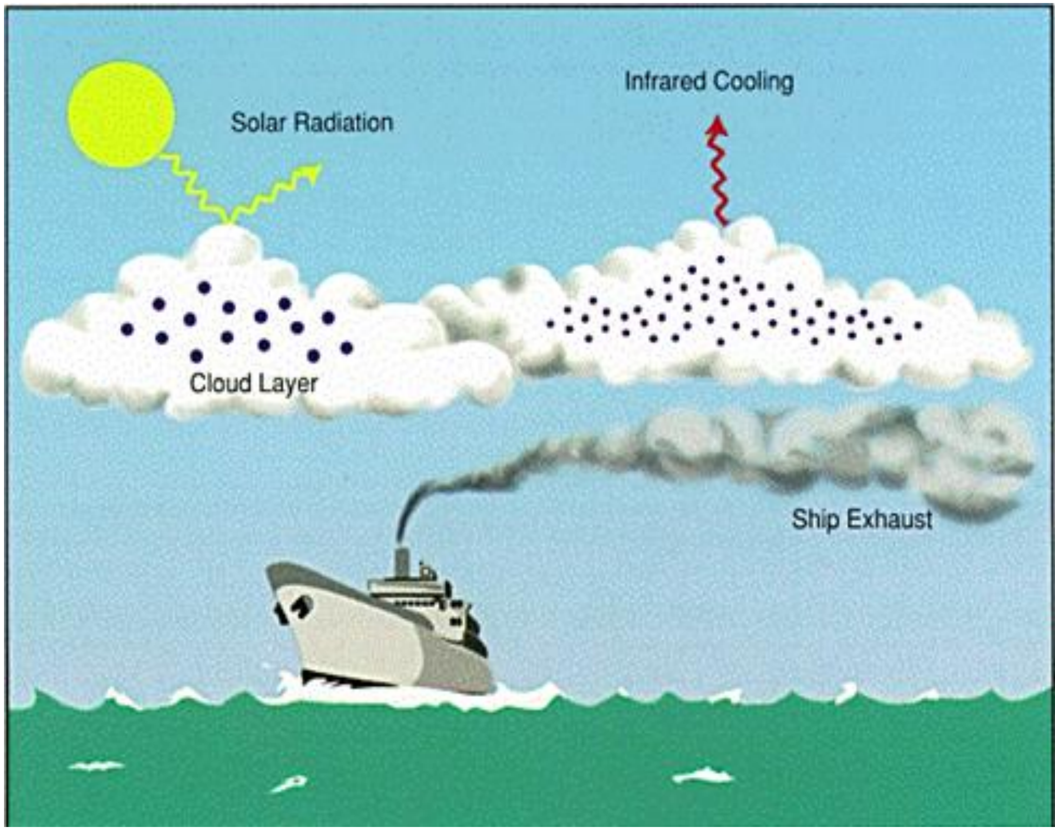
Small droplets

→ Strong reflection

Indirect effect

Number of CCN influences the droplet number and size (Twomey-Effect) and thereby the cloud albedo and lifetime.

'Ship tracks' visualise the indirect effect



Satellitenaufnahme (Wellenlänge: 3.7 µm)